Field Trial Tests the Sound Quality of ReSound LiNX 3D

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Tech Topic | January 2018 *Hearing Review*

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> In a field trial where recent purchasers of ReSound LiNX[2] were refit with ReSound LiNX 3D, subjective outcomes were slightly but significantly improved for ReSound LiNX 3D, with 70% of participants expressing a preference for the sound quality of the newer hearing aid.

What does good sound quality sound like? The answer to that apparently simple question can be quite different depending on who is asked and the context. Many people do not give much thought to the sound quality associated with the sound reproduction devices they use every day unless it interferes with their intent in listening. A corollary to this is that an individual's idea of good or acceptable sound quality is not absolute. For example, a telephone possesses few technical characteristics one would associate with good sound quality, like wide bandwidth and low noise floor. Yet people will judge the quality as good as long as they can hear the conversations well enough. That same level of quality in their television speakers would not be judged as acceptable, as the intent and expectation of the listening experience are different when watching television as opposed to talking on the phone.

Given that sound quality is personal, related to listening intent, and not absolute, it is easy to see why the concept of sound quality is complex and difficult to quantify when applied to hearing aids. Hearing aids are worn throughout the day in all kinds of environments and with all kinds of objectives in terms of listening. A hearing aid that provides a bass-heavy response might sound great to the wearer when purposefully listening to music, but annoying in other situations. To complicate matters further, hearing aids also reproduce sound that is already reproduced from telephones, televisions, radios, via streaming, and so on.

One controlled method for quantifying sound quality that has gained popularity in hearing aids uses a MUSHRA ("multiple stimulus" and "hidden reference and anchor") procedure.[1] This type of test is efficient in that it allows listeners to quickly switch back and forth among different conditions and to compare to the original sound. This helps overcome the limitations of auditory memory and limits bias due to other factors, such as fit or appearance of the hearing aids. It also allows listeners to focus on a particular dimension of sound quality in their judgments, such as "brightness" or "loudness."

Jespersen[2] described how a MUSHRA procedure was used to evaluate overall preference for sound quality in premium hearing aids, where ReSound hearing aids were consistently rated highly for sound quality. In addition, a pattern of attributes that were associated with sound

quality preference were identified. Hearing aids that were judged as being high in “naturalness” and “dynamics,” and very low in “distortion/artifact” were judged most favorably in overall sound quality.

Processing and Sound Quality

Sjölander and Groth[3] reviewed reasons behind the top-rated sound quality of ReSound hearing aids. A primary driver is the ReSound philosophy of sound processing that respects natural hearing processes. Because hearing is a job done by the brain, product development efforts are focused on emulating the ear to deliver the best possible signals to the brain. Sound processing technologies, such as Warp compression and Spatial Sense, are good examples of how this philosophy has been applied.

Another example is the unique approach to applying directional technology that ReSound has evolved over more than a decade, using directional technology to enhance natural listening strategies performed by the brain. By intelligent switching among four different microphone mode combinations, the Binaural Directionality approach is designed to ensure access to an improved signal-to-noise ratio (SNR) while preserving audibility and awareness of the surrounding sounds. Evidence shows improved SNR for sound from in front, but without the unnatural listening behavior imposed by the traditional way directional technology has been used in hearing aids.

Although directionality can improve speech understanding when speech is coming from in front of the user and noise is separated from the speech, it can interfere with hearing desired speech from other directions, following conversations in the real world, and maintaining orientation in the environment. Additionally, directionality traditionally introduces an imbalance in the response between low and high frequencies that can make the sound thin.[4] Therefore, traditional approaches to better hearing in noise have the side effect of creating an unnatural listening situation and negatively impacting sound quality in real-life environments. With the Binaural Directionality strategy, these drawbacks are avoided. Audibility is preserved for off-axis sounds, which is important not only for safety and for being able to reorient in the case of novel, interesting sounds in the environment, but also because one-third of hearing aid wearers’ active listening time is attending to sounds that are moving or that they are not looking at.[5]

In the design of ReSound LiNX 3D, three advancements were introduced with the intent to boost certain aspects of sound quality. In particular, the perception of “naturalness” and “dynamics” were expected to be enhanced. The first of these is a behind-the-scenes correction for open fittings that compensates for the small boost in gain that results from the open ear canal resonance. This change helps optimize the balance between low and high frequencies that enhances the perceived fullness of the sound.

The second change that contributes to the improvement in sound quality with ReSound LiNX 3D is a purposeful design difference to enhance spatial hearing when the hearing aids are in an asymmetric microphone mode, which is a significant amount of an individual’s wear time.

Apart from maximizing audibility of sounds that are not in front of the hearing aid wearer, this enhancement is intended to increase the individual's perception of spaciousness. This aspect of sound plays a significant role in the naturalness of sound. Put simply, it is what takes the perception of sound outside of the head of the listener, allowing them to perceive sound sources in space.

Spaciousness is associated with the perception of early reflections in the room and reduced interaural cross correlation (IACC)between the two ears. Early reflections from walls and surfaces in the environment contribute to our preferred impression of spaciousness.[4] Binaural Directionality III provides more uniform sensitivity to sounds from any direction than Binaural Directionality II. Because other hearing aids apply directionality bilaterally—and in some instances with reduced binaural cues due to the technology—this strategy is substantially different. The improvements in the ability to hear sounds not in front, an advantage of the Binaural Directionality III system, not only increase the user's ability to track alternative sound sources, but also increase the user's ability to be aware of the room acoustics around them. The awareness of room acoustics is a large determinant of the naturalness and quality of the sound.

A related effect that contributes to our sense of space is IACC. Briefly, this means how similar the sound detected at the two ears is. Sounds at both ears that are almost identical (highly cross-correlated) are associated with the source being directly in front of us, but provide no information about the surrounding space. It is this information about the surrounding space that contributes to the experience of natural sound quality. Thus, sounds with lower IACC between the ears are associated with an increased sense of the space around the source.[6-9] Binaural Directionality III does a better job than even Binaural Directionality II in maximizing the acoustic contrast of the sound at each ear, effectively reducing the IACC in reverberant environments and increasing the sense of space.

The final improvement in ReSound LiNX 3D is not directly related to sound quality, but affects the environmentally dependent settings of the hearing aids and, thus, impacts how the hearing aids process sounds in different types of environments. ReSound hearing aids use the output of a noise-detection module to control several sound processing algorithms, as well as to aid in estimating SNR, which is also a parameter in controlling some sound processing. The most aggressive sound processing in today's hearing aids is intended for noisy situations. However, practical experience has demonstrated that users are sensitive to such processing if it is aggressively applied in less -complex acoustic environments. Therefore, the ReSound approach to noise management has been, and continues to be, conservative. Stronger noise reduction and directional strategies are applied carefully, when the probability of noise in the acoustic environment is very high. The updated noise detection in ReSound LiNX 3D has been shown to allow for more accurate characterization of noisy environments.[10] This provides more and better opportunities to apply noise management strategies in everyday situations that are beneficial and not distracting for the user.

Studying Sound Quality in Real Life

Systematic and controlled methods for evaluating sound quality in hearing aids have value, but are necessarily limited in scope and interpretation. Results obtained using techniques such as MUSHRA provide valuable insights on attributes that contribute to sound quality and are helpful in evaluating the impact of changes to a product. Examples of such changes might include tuning the parameters of an audio streaming protocol or the settings of a listening program.

However, results may not be generalizable to real-world use and the typical hearing aid wearer. This is because a controlled test typically involves listening to recorded sounds through headphones, and listeners are often selected specifically for their keen ability to discriminate subtle sound differences. To reinforce the validity of findings under controlled conditions, it is also of interest to ask hearing aid wearers for their subjective impressions of sound quality in their daily lives, keeping in mind that they have their own internalized points of reference and criteria. In order to explore whether the enhancements to ReSound LiNX 3D really make a difference in terms of sound quality, a field trial with current ReSound LiNX^2 wearers was conducted.

Methods

Participants, hearing aids, and fittings. A total of 25 (9 female, 16 male; average age 70; age range 54-83) adults who were owners of bilaterally fit ReSound LiNX^2 RIE style hearing aids and clients of one audiology practice participated in this trial. Participants were recruited by sending ReSound LiNX^2 owners a letter inviting them to trial a new product under development by the manufacturer of their existing devices. Ownership of ReSound LiNX^2 ranged from 1-15 months with a median of 4 months. One male and one female participant did not complete the trial. In one case, the participant did not wear the hearing aids, and in the other case, the participant was not able to cooperate with all of the trial procedures. Average hearing level thresholds for right and left ears are shown in Figure 1.

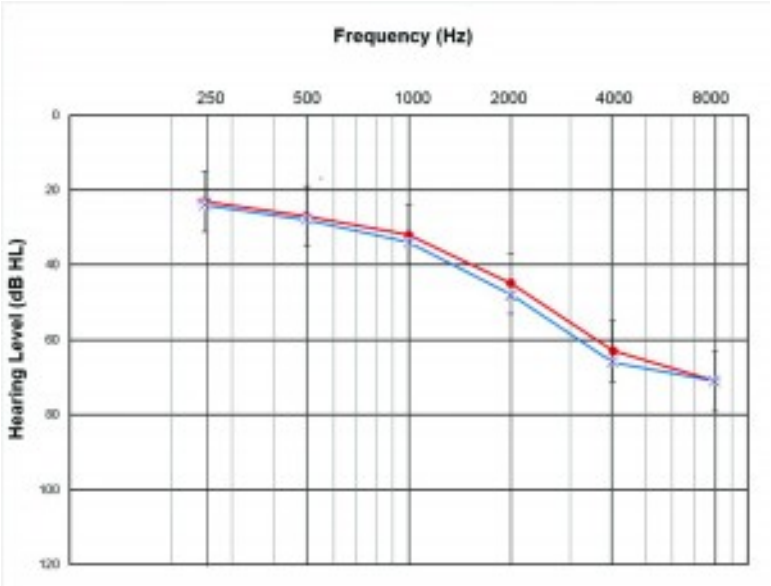

Figure 1. Average hearing level thresholds for right (red) and left (blue) ears of all participants. Error bars show one standard deviation for the right ears. Standard deviation for the left ears was nearly identical and omitted here for

readability of the graph.

The trial hearing aids were ReSound LiNX 3D. Participants were fit with the same model and receiver power level as their ReSound LiNX^2 fittings. In this way, there were no physical differences between the two sets of hearing aids apparent to the participants. Settings from the participants' own hearing aids were transferred to the ReSound LiNX 3D devices. Real-ear output was measured with a speech signal at 65 dB SPL to document the responses of the owned and trial devices. Participants wore the trial devices for 4-6 weeks, with one return visit halfway through the trial to address any issues that might have arisen.

Outcome measures included the QuickSIN,[11] the short form of the Speech, Spatial and Qualities of Hearing Scale (SSQ12),[12] and portions of the Hearing Aid Satisfaction Survey,[13] as well as subjective assessment. Participants indicated an overall preference at the conclusion of the trial.

Results and Discussion

Objective outcomes. Figure 2 shows the average real-ear output for a 65 dB SPL speech signal for ReSound LiNX^2 and ReSound LiNX 3D fittings. Because the ReSound LiNX 3D fittings were transferred from the ReSound LiNX^2 fittings, no average differences were anticipated. However, some individual variation due to the correction for open fittings in ReSound LiNX 3D was expected.

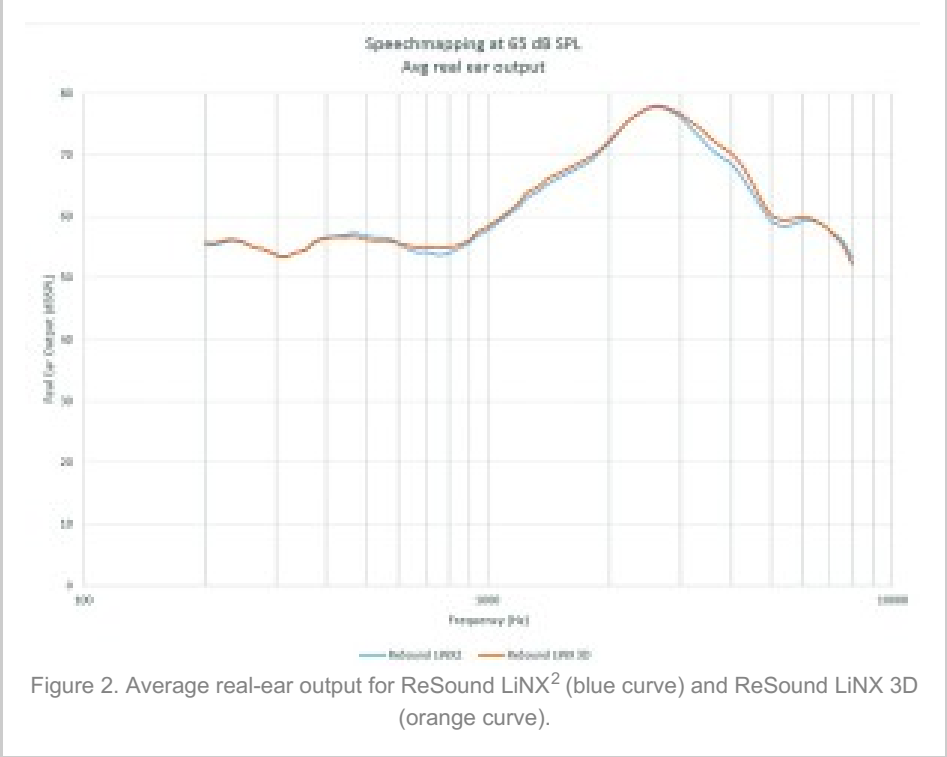

Figure 2. Average real-ear output for ReSound LiNX^2 (blue curve) and ReSound LiNX 3D (orange curve).

Although most of the fittings in this trial were open, the small correction between ReSound LiNX^2 and ReSound LiNX 3D is not apparent in averaged measurements when the gain settings are all different among fittings. For individual ears where the gains were identical in

the two sets of hearing aids, the open fit compensation that reduces the peak at 3 kHz was apparent (Figure 3).

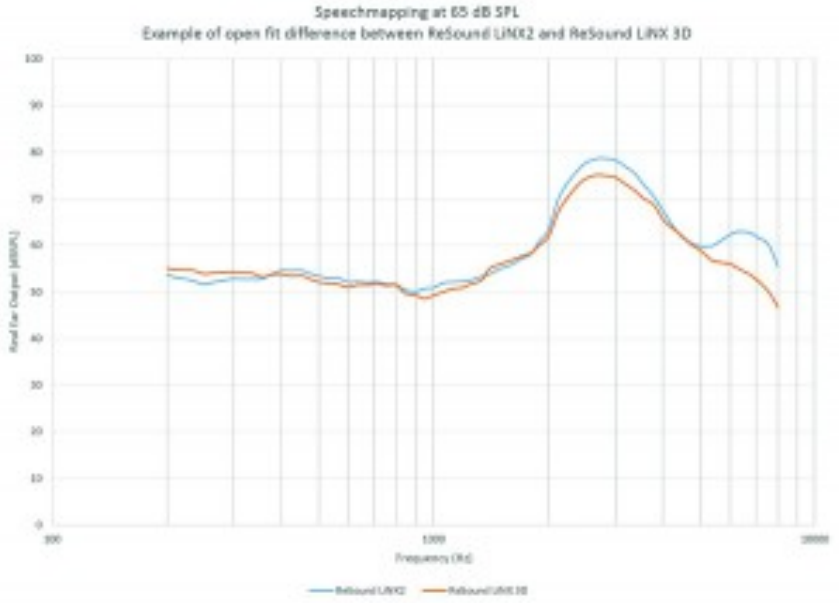

Figure 3. Example of an individual open fit ear where the peak reduction at 3 kHz is apparent for ReSound LiNX 3D (orange curve).

Because the ReSound LiNX 3D fittings were duplicated from LiNX^2 fittings, no differences were anticipated or demonstrated on the QuickSIN.

Data Logging and Binaural Directionality III. The average total hours of use of the ReSound LiNX 3D hearing aids during the trial period were 502 hours, ranging from 187 hours to 697 hours. All participants wore the bilaterally fit hearing aids approximately equally on both ears.

In addition to hours of use, data logging also shows a breakdown of the acoustic environments that are encountered, as well as the percentage of time spent in the four possible microphone modes for Binaural Directionality III. By comparing these, it is possible to get an impression of whether microphone mode switching is appropriate. Bilateral directional or asymmetric directional modes should be active in environments that are identified as “noise” or “speech in noise.” Figures 4 and 5 show the average percentage of time logged in different environments. “quiet,” “soft speech,” and “moderate speech” are combined to facilitate comparison to logging of the time spent in different microphone modes. It is expected that percentage of time in quiet and speech environments would correlate with the hearing aids being in bilateral omnidirectional mode. This expectation was confirmed by the results. Time spent in quiet and speech environments averaged 45% and time in bilateral omnidirectionality averaged 46%. Likewise, time spent in noisy environments averaged 55% and an average of 54% of use time was in an asymmetric or bilateral directional mode.

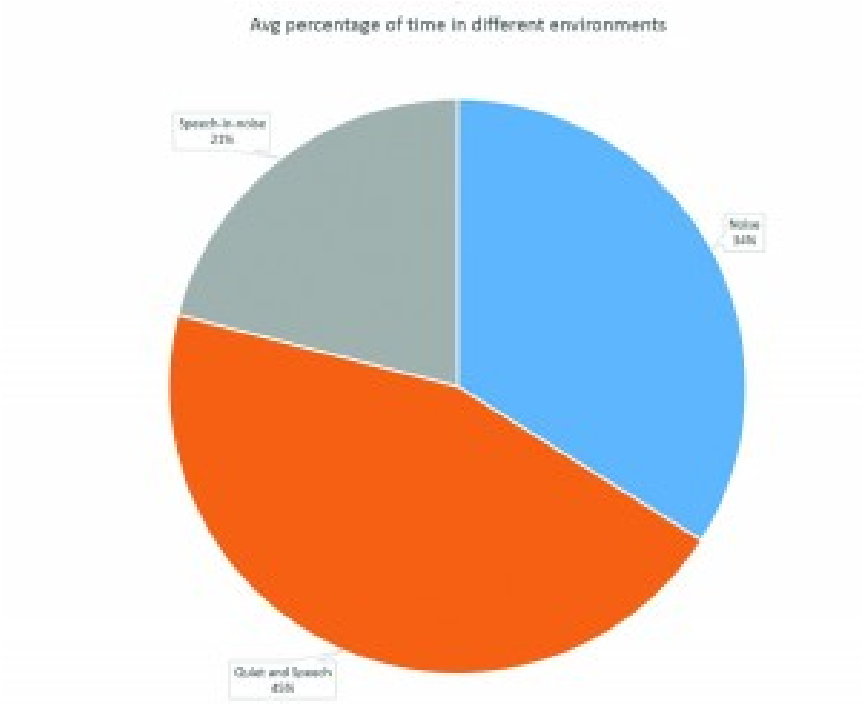

Figure 4. Average percentage of time spent in different acoustic environments in the default program (Binaural Directionality III).

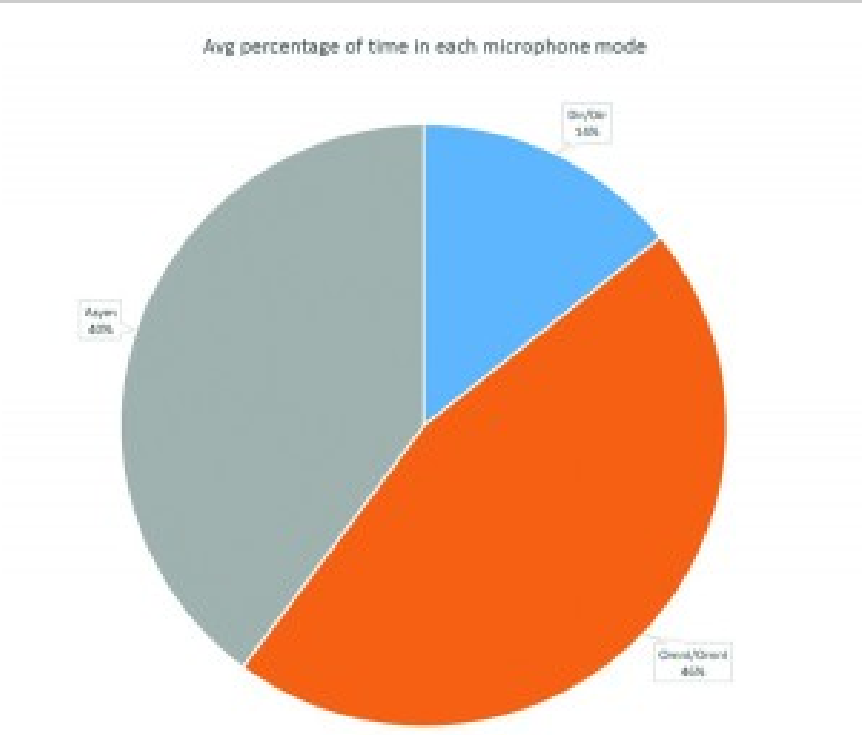

Figure 5. Average percentage of time in each of the four microphone modes of Binaural Directionality III.

It is of note that the average data from the environmental classifier, as well as the Binaural Directionality III data, differed significantly from what has been observed with previous product generations. For example, a data set collected with Binaural Directionality (introduced with ReSound Verso) showed the vast majority of time (77%) was spent in bilateral omnidirectional

microphone mode. In the current trial, only 46% of the time was in this mode. In both previous products, as well as the current trial, time spent in quiet and speech-only environments correlated well with time spent in bilateral omnidirectionality. This difference is due to the improvement in the noise detector module that influences both the environmental classifier as well as the environmental information that steers the microphone mode switching in Binaural Directionality III. The increased sensitivity to noise results in more environments being logged as containing noise, and also in triggering more time in asymmetric directional microphone mode. For both the data set obtained with ReSound Verso and the current trial with ReSound LiNX 3D, the average percentage of time spent in bilateral directionality was 14%. Taken together, this is a positive finding, as it indicates an increased potential for directional benefit during use of the hearing aids.

Subjective outcomes: Questionnaires. The SSQ12 asks about ability to locate sounds, ability to follow conversations in different types of environments, and ability to discriminate among different types of sounds (eg, making out which musical instruments are playing when music is heard). The nature of some of the questions suggests that this questionnaire may be suitable for documenting improvements made in the Binaural Directionality feature for ReSound LiNX 3D. A small but significant improvement was noted for ReSound LiNX 3D compared to ReSound LiNX^2. Figure 6 shows the results per subscale.

Figure 6. Average ratings for the three subscales of the SSQ.12 ReSound LiNX 3D was rated approximately one scaling unit better than ReSound LiNX^2 on all questions.

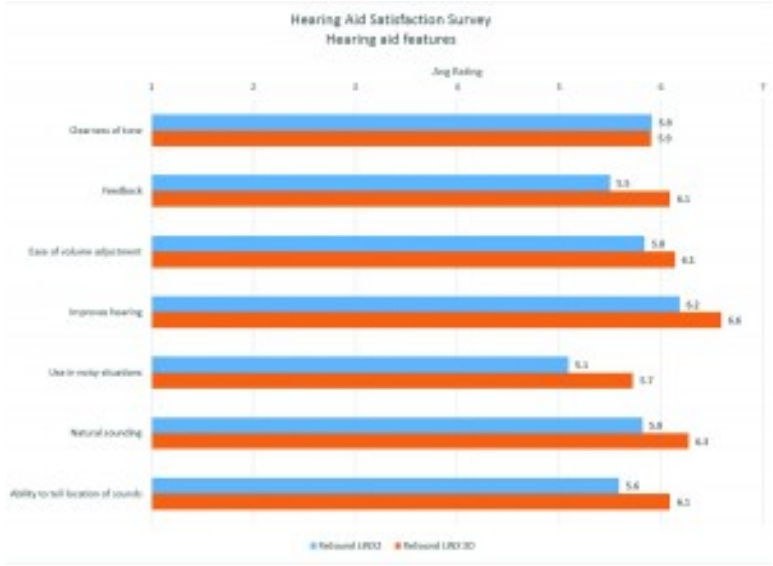

Figure 7. Average ratings for satisfaction with hearing aid features.

Figure 8. Average satisfaction ratings with the hearing aids in different listening situations.

The Hearing Aid Satisfaction Survey (HASS) is the questionnaire used to assess satisfaction with hearing aids in the MarkeTrak and EuroTrak surveys. Figure 7 shows the results for hearing aid features that are related to sound. Fit/comfort, visibility, size, ease of battery change, and appearance were not rated significantly different for ReSound LiNX 3D and ReSound LiNX^2, which is unsurprising because ReSound LiNX 3D reuses the ReSound LiNX^2 hardware design and, thus, would not affect satisfaction with physical factors. Sound-related features were rated slightly higher for ReSound LiNX 3D. It should be noted that all of these ratings, including those for the ReSound LINX^2, were quite high, suggesting some ceiling effects may have played a role.

The HASS also asks about satisfaction with the hearing aids in different listening situations. The ratings for ReSound LiNX 3D were slightly and significantly higher than those for ReSound LiNX^2 in all categories except church/synagogue (Figure 8).

Subjective outcomes—preferences, comments, and willingness to upgrade. A total of 16 of the 23 participants (70%) who completed the trial expressed an overall preference for the ReSound LiNX 3D devices. Reasons for their preferences are shown in Figure 9. Some gave multiple reasons, which means that the total number of reasons is greater than 16. Of the 7 who preferred ReSound LiNX^2, 5 reported that their preference was based on not perceiving a difference compared to ReSound LiNX 3D. In addition, one indicated hearing better with ReSound LiNX^2, and one liked the sound quality of ReSound LiNX^2 better.

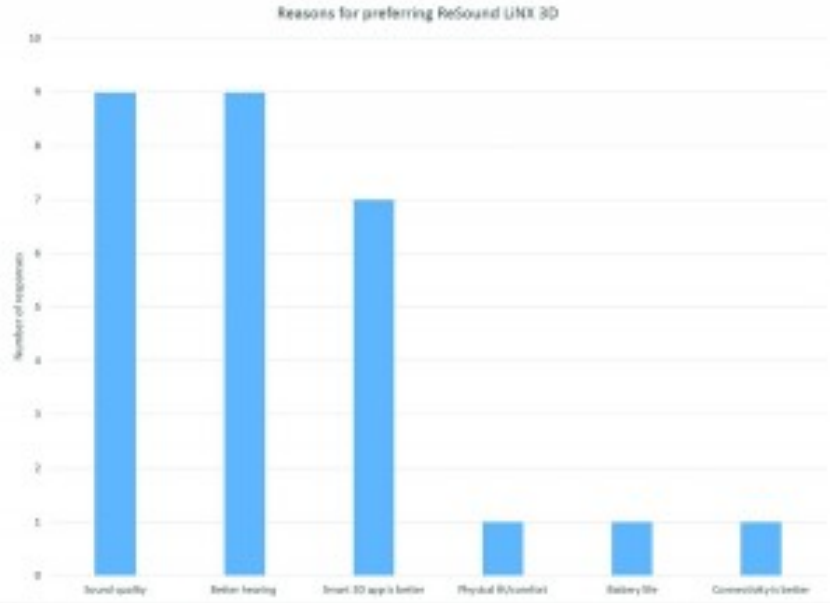

Figure 9. The 16 participants who preferred ReSound LiNX 3D over ReSound LiNX^2 gave these reasons for their preference. Individuals sometimes indicated more than one reason.

Participants gave both general comments and specific examples of situations where they perceived different performance of the two sets of hearing aids. Comments that were positive for ReSound LiNX 3D included:

- Better clarity;
- Better in wind noise;
- Cleaner sound–don't hear the fans at work;
- Wife says he hears better;
- Better localization–can tell where birds or alarm signals are coming from;
- Louder and stronger;
- "Not leaps and bounds better, but definitely worth a little more."

Comments in favor of ReSound LiNX^2 included:

- Sound quality good;
- Very good for TV, and
- Hear better with ReSound LiNX^2.

It is of note that a significant number of participants included the app as an influence on their experience, even though the app was not formally part of the study. Fifteen of the participants

owned smartphones, and 13 of these were iPhones. Increased ownership of smart devices is an observed trend in all age groups. Therefore, this high proportion of ownership is not entirely surprising. Fourteen of the 15 smartphone owners in this trial also installed and reported use of the ReSound Smart 3D app.

Although evaluation of the ReSound Smart 3D app was not an objective of this trial and participants were not specifically instructed in app usage, those who installed and used it spontaneously remarked that they found it to be better than the ReSound Smart app, and that the quick buttons were particularly useful to them. The quick buttons are named “speech clarity” and “noise filter.” The combinations of adjustments made by clicking these buttons are possible to achieve manually in the app, but the buttons provide a shortcut to doing so. Participants seemed to understand intuitively the purpose of the buttons and reported using them in appropriate situations. Examples of the use of the speech clarity button included in large groups, at a wedding, or when it was difficult to see the face of the desired talker. The noise filter button was reportedly used in situations where environmental sounds were perceived as annoying noise, such as computer fans and forced air climate control systems. One participant preferred ReSound LiNX 3D solely on the basis of the ReSound Smart 3D app.

At the conclusion of the trial, participants were offered the opportunity to purchase the ReSound LiNX 3D hearing aids for an amount corresponding to approximately 10% of what they had paid for ReSound LiNX^2. Considering that benefit and satisfaction with ReSound LiNX^2 was high, willingness to spend extra money to upgrade after only a short period of ReSound LiNX^2 ownership supports added perceived value. A total of 15 of the 23 participants (65%) elected to pay the extra amount to purchase the ReSound LiNX 3D hearing aids.

Summary

Sound quality relative to hearing aids is complicated to assess. Controlled methods have been developed that provide valuable information, especially regarding which dimensions of sound quality may contribute or detract from user preferences. However, preferences in everyday situations can differ even within individuals. While ReSound hearing aids have been shown to provide preferred sound quality using controlled methodology, it is also of interest to assess whether users judge sound quality improvements as significant in their everyday lives. ReSound LiNX 3D introduced three advancements intended to enhance the perceived naturalness and dynamics of sound quality. In a field trial where recent purchasers of ReSound LiNX^2 were refit with ReSound LiNX 3D, subjective outcomes were slightly but significantly improved for ReSound LiNX 3D, and 70% of participants expressed a preference for the ReSound LiNX 3D sound quality.

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Citation for this article: Groth J, Hartenstein R. Field trial tests the sound quality of ReSound LiNX 3D. *Hearing Review*. 2018;25(1):36-40.