The technical proof for clearer, fuller and richer sound with ReSound LiNX Quattro

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ABSTRACT

Sound quality is a key driver of consumer satisfaction with hearing aids. With a dramatically enriched new platform, ReSound LiNX Quattro adds industry-leading capabilities in input dynamic range and frequency bandwidth to its unique sound processing strategy to enable fuller, clearer and richer sound. This paper presents details on how this new platform enhances the performance of ReSound LiNX Quattro technically. A companion paper[1] presents perceptual results from listeners who compared ReSound LiNX Quattro with other premium hearing aids.

The benefits of amplification are traditionally defined in terms of better audibility for speech and environmental sounds. However, sound quality is a key driver of overall consumer satisfaction with hearing aids and is high on the wish lists of both hearing aid users and Hearing Care Professionals (HCPs). Approximately 40% of persons with moderate-to-severe loss would be motivated to purchase new hearing aids given better sound quality[2]. And according to ReSound market research, 452 independent HCPs in the US, France and Germany named sound quality to be the top attribute to consider in recommending hearing aids to users. Thus, it is important to focus on sound quality in hearing aid development in addition to other benefits. This is a complicated matter, as there is no consensus on what sound quality actually means or how to evaluate it. Regardless, it is certain that sound quality is a subjective experience that is perceived individually, and that it is considered of great importance.

At ReSound, our development is guided by emulating nature's time-tested patterns and strategies. This approach inherently leads us in the direction of "naturalness". In technical terms, sound reproduction that is natural would be equivalent to the sound being transparent acoustically. This means that the sound can be evaluated objectively by comparing its fidelity to the original sound. However, hearing aids deliberately change the sound relative to the original for hearing loss compensation. Thus, fidelity alone cannot be the sole criterion for sound quality. Decisions are needed to determine the optimum degree of transparency. This balance is dependent both on the listening environment as well as the individual. Naturalness can also refer to behavior, and this is also carefully considered in our hearing aid designs. For example, when in a conversation with others, it is natural to be able to follow the conversational turn-taking and to shift attention at will. Our goal is for hearing aids to allow the sound to be perceived as natural, but also for the wearer to be able to behave in a natural way in their daily listening environments.

The ReSound LiNX Quattro takes sound quality to a new level. The processor core is a complete re-design from previous processor generations and takes an industry-leading position. It has been dramatically enriched to maximize processing efficiency and audio quality. To take full advantage of the advanced processing capabilities, all sound processing algorithms have been rewritten for efficiency, quality, and maximum benefit. Sounds are fuller, clearer and richer than ever before. This paper focuses on how technical properties and advances enable the perception of excellent sound quality with the ReSound LiNX Quattro. Perceptual evaluation of sound quality demonstrating the preferred sound quality of ReSound LiNX Quattro is considered in a companion paper[1].

A NEW PLATFORM

No one feature or characteristic of a hearing instrument can ensure satisfactory sound quality. Mechanical and electroacoustic designs are critical components of how the final product performs and sounds. For today's digital hearing aids, sampling rate, A/D conversion, and processing speed are some additional factors that can affect the sound output of the hearing instrument, either directly or by means of what sound processing they enable. The characteristics and advantages of the advanced platform for ReSound LiNX Quattro are summarized in Table 1. In addition to these improvements, doubling the memory capabilities of the platform has enabled additional features in the ReSound LiNX Quattro.

Characteristic	What it means	Advantage for ReSound LiNX Quattro
A/D conversion (bits)	Defines the range of sound levels that can be digitized with no distortion	Makes full use of the capability of the microphones and enables the industry's highest input dynamic range of 116 dB SPL
Resolution (bits)	Refers to the length of the digital "words" describing the signal; better resolution provides a more accurate reproduction of the sound	Best-in-class audio resolution on par with pro-audio applications, supporting the best sound quality
Processor speed (MHz)	Coordinates arithmetic operations and data transfer	Double the speed of previous ReSound technology provides maximum efficiency for running sound processing and other hearing aid functions
Configurable sampling rate	How often the incoming signal is sampled per unit of time	Allows extended high frequency bandwidth with clean representation of high frequencies
Dual core processing with new radio	Dedicated processors handle wireless functionality and sound processing separately	New radio gives up to 5 dB better sensitivity for better ear-to-ear performance
Power efficiency	20% better efficiency than previous ReSound platform	Enables use time per charge of two full days for rechargeable solution

Table 1. Overview of the ReSound LiNX Quattro platform characteristics.

Digital hearing aids have been around for more than two decades. Initially, the label "digital" was used as a promotional term to market hearing aids featuring digital sound processing, and the implication was that sound quality would be vastly improved. Ironically, the digital technology of those first devices imposed limitations that in some ways actually made them inferior to many programmable analog hearing aids of the time. An example of such a limitation was the maximum sound levels that could be digitized without distortion. Typically, sounds with levels nearing 100 dB SPL or greater would be clipped after entering the microphones. This would add a great deal of distortion to the signal that was processed by the amplifier, and resulted in significantly degraded sound quality. As digital technology in hearing aids advanced, such issues were mitigated, although not completely solved.

Input dynamic range is one limitation that is solved in ReSound LiNX Quattro. For the first time, the full range of sound that is made available by the Micro-electric-mechanical systems (MEMS) microphones can be utilized, resulting in a clean signal passed to the amplifier. The hearing aid grade MEMs microphones can transduce very high sound levels and are small, highly consistent in performance, and resistant to environmental conditions. These properties make them ideal for use in hearing aids with advanced directional processing. Consistent and stable microphone performance is essential for continued benefit of the unique Binaural Directionality III strategy[3] over the lifetime of the hearing aids.

One type of sound for which the input dynamic range of the hearing aids makes an enormous impact on sound quality is music. While the primary goal of hearing aid design and use is to hear and communicate with others, the hearing aid's ability to faithfully reproduce music is the ultimate test of its sound quality. While there are other acoustic differences between speech and music, what is significant relative to the input range of the hearing aids is that music has a higher crest factor* than speech and is often more intense[4]. Adding to this is the tendency for loudness levels for music to be lower than for speech; that is, a level which is judged as "loud" for speech will be judged less loud for music[5]. The implication is that people will typically listen to music at higher levels, with increased risk of exceeding the input dynamic range of the hearing aids. Figure 1 illustrates how a system with a reduced input dynamic range can clip the peaks of a signal. In this example, violin music was used. It is obvious visually how the signal components above a certain level are cut off. The audible difference is that the music recorded through the system with the reduced input dynamic range sounds "fuzzy" relative to the one with the higher range that does not clip.

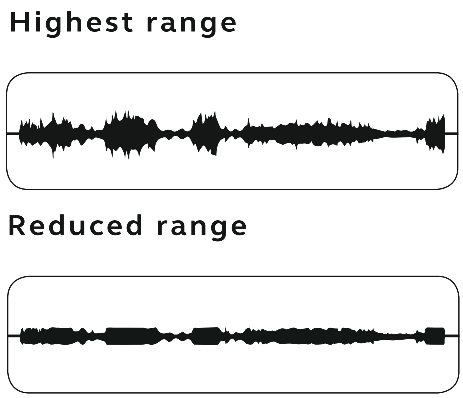


Figure 1. A waveform of classic violin music played through a hearing aid with a high input dynamic range (upper panel) and a reduced input dynamic range (lower panel). The clipping of the signal peaks in the waveform of the lower panel result in a great deal of added distortion that cannot be eliminated by other hearing aid processing.

EXTENDED HIGH FREQUENCY RESPONSE

One of the determinants of sound quality in any sound reproduction system is the frequency response. The frequency response encompasses both the range of frequencies that are reproduced as well as how smooth or peaky the response is. In terms of smoothness, a goal of the electroacoustic design of hearing aids is to achieve a frequency response that results in flat insertion gain across the range of amplified frequencies. The range itself is also part of this

* Crest factor is the difference between the peak value and overall rms value of a signal. It is an indication of how extreme the peaks are in a signal.

design. While the selection of components, design of the mechanics, and calibration of the system determine the final usable frequency range and the shape of its response, it is the digital platform that sets the theoretical limit for how wide the range can be. Because the sampling rate of the sound can be increased by more than 50% with the new platform, it is possible to extend the frequency range of ReSound LiNX Quattro relative to previous ReSound hearing aids. With the selected configuration of sampling rate, a bandwidth extending to 9.5kHz is made possible.

Hearing aids have traditionally been limited in their ability to reproduce high frequencies. However, evidence has built to suggest that frequencies above this traditional bandwidth limitation are more important to speech perception and sound quality than previously assumed. Therefore, it is considered desirable for hearing aids to be able to amplify at higher frequencies. Contributions of high frequencies beyond the typical bandwidth up to 7 kHz include speech, voice and overall quality[6,7], source localization[8], speech intelligibility[9], identification of talker[10], and word learning in children[11]. Apart from increased audibility of higher frequency sounds that is possible with extended high frequency bandwidth, all other features are also impacted by the availability of additional high frequency information. Some, such as Spatial Sense, Sound Shaper, and streaming capabilities are of particular interest.

IMPACT ON SPATIAL SENSE

Spatial Sense preserves and aligns localization cues that result in externalized sound. When sound is not externalized, it sounds similar to wearing headphones where the sound is perceived as being inside the head. Externalized sound means that the sound environment is perceived in a natural-sounding way rather than within the listener's head. Spatial Sense plays an important role in Binaural Directionality III. In listening situations that are quiet or that only consist of clear speech, Binaural Directionality III will activate Spatial Sense bilaterally to ensure the best sound quality.

Spatial Sense accounts for the three hearing instrument-related issues that can interfere with spatial cues that are especially salient in the high frequencies:

1. Placement of the microphones above the pinna in Behind-the-Ear (BTE) and Receiver-in-the-Ear (RIE) styles removes spectral pinna cues[12,13].

2. Placement of the microphones above the pinna in BTE and RIE styles distorts Interaural Level Difference (ILD)[14].

3. Independently functioning Wide Dynamic Range Compression in two bilaterally fit hearing instruments can distort ILD[15].

Spatial Sense[16] is modeled after the natural ear. This model includes a pinna restoration algorithm that preserves monaural spectral cues important for front-to-back and vertical localization. Increased bandwidth above 6 kHz contributes positively to localization ability[17]. As can be seen in Figure 2, the additional high frequency bandwidth of the ReSound LiNX Quattro compared to previous ReSound hearing aids gives access to a more complete pattern of spectral cues that emulate those of the natural pinna.

Pinna restoration high BW

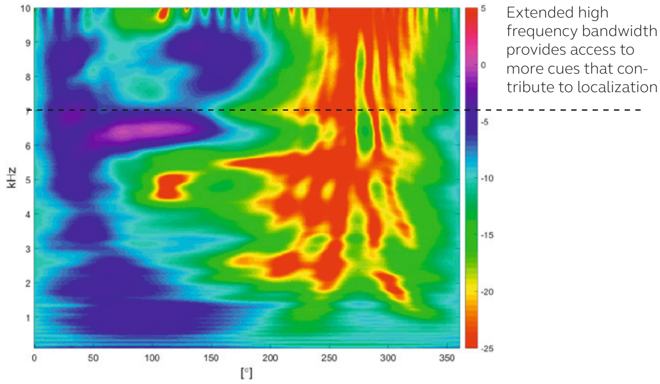


Figure 2. In this chart, color represents the intensity of the sound as a function of angle of incidence (x-axis) and frequency (y-axis). The pattern of spectral cues provided by the pinna is more extensive with ReSound LiNX Quattro. The dotted line shows the upper bandwidth frequency for previous ReSound hearing aids. The cues above this cut-off would be unobtainable with earlier technology. The additional frequency bandwidth also contributes to an improvement of 1 dB in the estimation of ILD compared to previous technology.

The pinna restoration algorithm also forms the critical basis of the other component of Spatial Sense, which is binaural compression. This part of Spatial Sense assists in localizing sounds that occur on the left or right. This kind of localization is based in part on comparing the level differences between ears (ILD), and is also a high frequency cue. When ILD cues are consistent with interaural phase cues, externalization of sound occurs perceptually. Pinna restoration is used to estimate the ILD. Then, wireless exchange of information emulates the crossing of signals between ears, and the correction of ILD based on the ear with the least intense signal mimics inhibitory effects of auditory efferents. Due to the preserved localization cues extending to an even wider frequency bandwidth than previously in addition to other optimization of the algorithm, the average ILD error is reduced from 4.5 dB without Spatial Sense to .7 dB with Spatial Sense. This is a further improvement of about 1 dB compared to Spatial Sense in ReSound LiNX3D.

IMPACT ON SOUND SHAPER

Sound Shaper uses frequency compression to improve audibility of high frequency sounds – especially speech sounds – in cases where traditional amplification is limited[18]. Such limitations may occur because the nature of the cochlear damage prevents the individual from being able to interpret the high frequency information. This is thought to be an issue with so-called "dead regions" of the cochlea[19]. Technical limitations associated with the hearing aid or fitting may also prevent sufficient amplification to make soft, high frequency speech sounds audible. Sound Shaper is a fitting option which benefits some individuals in terms of increased audibility of high frequency sounds and/or sound quality. In addition to the three settings that were available in earlier ReSound hearing aids, a "Very Mild" setting with a cut-off frequency of 5 kHz and an output bandwidth extending to 8.5 kHz widens the range of users who might experience benefit from this technology.

BENEFITS EXTEND TO STREAMING

The sound quality benefits associated with the extended bandwidth capabilities of ReSound LiNX Quattro apply to streaming of audio as well. ReSound wireless accessories have always had a wide streaming bandwidth, with some up to 10 kHz, and with ReSound LiNX Quattro, the hearing aid can fully reproduce the bandwidth of the streamed signal. As part of the ReSound ecosystem, ReSound LiNX Quattro is compatible with existing wireless accessories. So, for example, a current ReSound LiNX user who owns a TV Streamer 2 and upgrades to ReSound LiNX Quattro can still use their streamer with their new hearing aids. At the same time, the directly streamed sound to which the user has become accustomed will be further improved by the bandwidth capabilities of the new platform.

Like its predecessors, ReSound LiNX Quattro is also an MFi hearing aid, meaning that it is certified to work with Apple devices such as the iPhone, and can stream audio directly from these devices. As the first hearing aid manufacturer to implement this capability, ReSound has unique access to higher streaming bandwidth from these devices compared to MFi hearing aids that have since been introduced. Figure 3 shows the responses of four MFi hearing aids that were programmed as similarly as possible with flat linear gain, and presented with white noise streamed from an iPhone. Despite that the other MFi hearing instruments are capable of reproducing higher frequencies, the measurements demonstrate that the signal bandwidth is restricted. Only the ReSound LiNX Quattro (red curve) shows bandwidth that corresponds to the capabilities of the hearing aid.

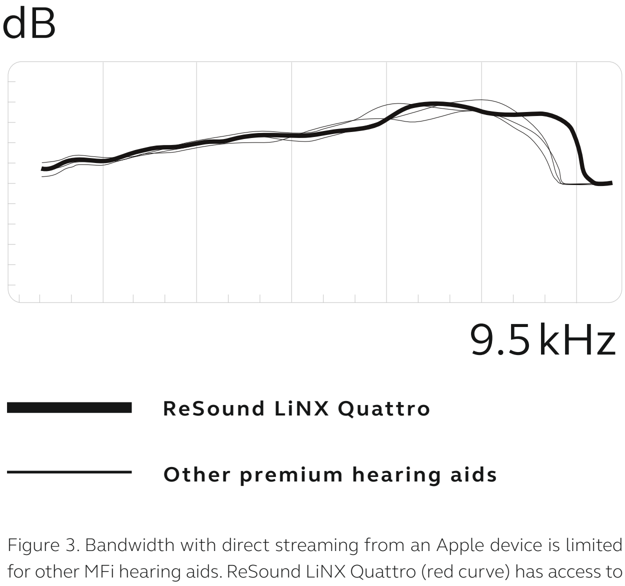


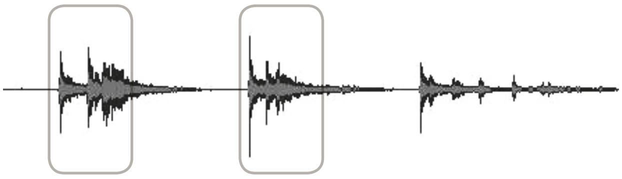
Figure 3. Bandwidth with direct streaming from an Apple device is limited for other MFi hearing aids. ReSound LiNX Quattro (red curve) has access to a broader streaming bandwidth, contributing to sound quality.

SOUND QUALITY FOR NEW USERS

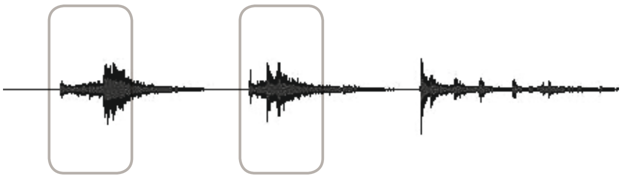
New users, especially those who wait to seek amplification until their hearing loss has progressed to moderate levels, have been shown to prefer less gain than those experienced hearing aid users. Further, it may take two years or more for a new user to adapt to prescribed levels of amplification[20]. For this reason, ReSound provides fitting tools for helping those new to amplification adjust to hearing aids. The HCP can either apply a user profile that will reduce high frequency gain and increase compression ratios slightly, or simply apply a percentage of the prescribed gains to the initial fitting. Gains can gradually increase to prescribed levels automatically over a period of usage by activating the Acceptance Manager. Or gains can be increased manually at follow-up appointments or via ReSound Assist as the user becomes accustomed to the sound.

Apart from prescribed gains, those new to hearing aids may be especially sensitive to dynamic aspects of the amplification. The ReSound Warp compression system uses syllabic time constants by default to increase the audibility of soft speech sounds. Although some speech sounds - such as “t” or “k” sounds - are transient in nature, the instantaneous change in energy associated with production of these sounds is limited and the Warp compression system can amplify them appropriately. Other types of transient sounds have a more rapid rise and fall in sound level than speech sounds, and can be annoying for users when heard through the hearing aids. These are not the very loud “slamming door” type sounds that might trigger output limiting. And, as mentioned, they are not the softer transient speech sounds that are critical to understanding speech. Instead, sounds that are relatively loud and significantly above the background levels, like clanking dishes or jangling keys, can be of annoyance. This is due to compression time constants that may not keep up with this type of sound, resulting in a very brief period of more-than-prescribed gain when such sounds occur. Although this overshoot in amplification does not exceed uncomfortable levels, it can contribute to a perception of tinny or sharp sound quality that is a common complaint of those new to hearing aids.

ReSound LiNX Quattro introduces Impulse Noise Reduction to prevent this issue by keeping gains at prescribed levels for brief transient sounds that might be of annoyance to users. Impulse Noise Reduction recognizes transient sounds that have rise times and energy levels which are too rapid to be speech, and is judiciously applied in such cases. Figure 4 shows the acoustic effect of Impulse Noise Reduction. Recordings were made with a ReSound LiNX Quattro programmed to a moderately severe hearing loss. The top panel shows part of the waveform for the amplified sound of plates being stacked without Impulse Noise Reduction activated. The bottom panel shows the same sound processed with Impulse Noise Reduction activated. While the reduction of the sharp, brief peaks is easy to observe on the waveform, the perceptual effect is subtle. This feature is especially useful when fitting new users because they are often fit with greater compression ratios that ensure listening comfort at louder sound levels, but that can exacerbate overshoot for impulse sounds.



Without impulse noise reduction



With impulse noise reduction

Figure 4. Impulse noise reduction works in parallel with the Warp compression system to ensure that transient sounds are not overamplified. Soft transient speech sounds are preserved. In this example, the sound of plates being stacked was recorded through a ReSound LiNX Quattro hearing aid with (bottom panel) and without (top panel) impulse noise reduction active. The light blue boxes show how peaks where overshoot occurs are reduced with impulse noise reduction.

ENHANCED CARE

As a leader in innovation, ReSound was the first to introduce a tool that makes use of cloud-based technology that allows the HCP to provide more complete care and strengthen the relationship with the hearing aid user. ReSound Assist[21] is a follow-up tool that enables users to make requests or ask questions to their HCPs via the ReSound Smart 3D app on their smartphones. HCPs receive these requests via ReSound Smart Fit software, and can respond with messages and/or fine-tuned adjustments that the user can download wirelessly to their hearing aids from their smartphones. HCPs receive requests along with information on the current hearing aid settings which can be especially informative and helpful when the user sends a request from a listening environment where they are challenged. In addition, HCPs receive a regular log of hearing aid usage from their clients' hearing aids, allowing them to proactively follow-up to encourage users who may be having issues but who may be hesitant to report them.

SUMMARY

Although sound quality is problematic to quantify, it is highly desired by hearing aid users, and is considered a crucial attribute of hearing aids by HCPs. The ReSound philosophy for hearing aid design is to provide acoustic transparency balanced with processing for hearing loss compensation such that the listening experience is both natural and clear. With a completely new platform, Resound LiNX Quattro leads the industry with the highest input dynamic range, and extended high frequency bandwidth. These new capabilities have comprehensive and measureable positive effects for both acoustic and streamed inputs. As a result, users can experience fuller, clearer and richer sound than ever before.

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CVR no. 55082715

M201431GB-18.08-Rev.B