

Hearing aid users show preference for ReSound Impulse Noise Reduction

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ABSTRACT

Modern hearing aids with input level dependent amplification and noise management features like digital noise reduction and directionality have improved hearing aid users' comfort with loud sounds. Impulse sounds, which have an abrupt onset, may still be bothersome or uncomfortable for users because they occur too rapidly to be amplified correctly by hearing aids. While some impulse noise reduction features exist, they reduce gain at all frequencies, which can negatively impact sound quality. ReSound Impulse Noise Reduction is uniquely designed to use individual fitting data together with environmental information to immediately reduce the level of impulse noises while preserving speech audibility and sound quality. This paper discusses the importance of ReSound Impulse Noise Reduction and describes results that support how it supplements the overall noise management strategy in ReSound hearing aids.

Imagine that you are absorbed in reading a good book when suddenly your pet knocks something off a shelf behind you and it crashes to the tiled floor. Most anyone would jump or flinch in reaction to this scenario, but for hearing aid wearers the shock can be even greater. This is because hearing aids can apply too much amplification to sounds that occur very suddenly. An abrupt sound that is startling to a normal-hearing person has the potential to be very distressing for a hearing aid wearer. ReSound Impulse Noise Reduction is a signal processing technology that can improve the listening experience for hearing aid wearers by increasing comfort for abruptly occurring sounds. ReSound Impulse Noise Reduction has a unique design that reduces the gain overshoot that can occur for rapid onset sounds while avoiding sound quality issues that can occur with typical impulse noise reduction processing.

HEARING AIDS HELP, BUT CAN BE ANNOYING

Hearing aid owners have attributed disuse of their hearing aids at least partly to amplified sounds being annoying. A quarter of hearing aid owners who stopped using their hearing aids indicated that it was because the hearing aids did not meet their expectations in noisy backgrounds. Dissatisfaction with hearing aids in noise encompasses many specific issues, such as not being able to follow conversation in noise and loud sounds being amplified too much. At least some dissatisfaction is particularly related to abrupt

sounds. One hearing aid owner described it this way: "If someone drops a spoon on the table it is like a rifle going off."¹

Brief sounds such as a spoon dropping on a table are generally categorized as impulse sounds. This type of sound has a sudden onset with one or more bursts of acoustic energy at high amplitudes and with a broad spectral density. Clattering cutlery and dishes, clapping, keys jangling, and a car door shutting are examples of impulse sounds that occur daily for most everyone. New hearing aids users who logged the noises they encountered reported that transient noises made up about 1/3 of the total.² Furthermore, these users reported that this type of sound was often experienced as annoying. While one might think that noises which are only present briefly would be less annoying than those that have a longer duration, the participants in this study rated the annoyance of impulse sounds approximately the same as more constant noises.

IMPULSE SOUNDS AND HEARING AIDS

Virtually all hearing aids today use a compression scheme based on Wide Dynamic Range Compression (WDRC). The intention in using WDRC is to fit the wide range of audible sound into the individual dynamic range of the user, and involves amplifying softer sounds more than louder sounds. A benefit of WDRC in terms of listening comfort

is that sounds may be less aversive due to the input level dependent amplification. Normative data for the Abbreviated Profile of Hearing Aid Benefit³ for hearing aid users fit with WDRC support that this is the case. Compared to earlier normative data gathered from users of linear amplification, less negative reactions to amplified environmental sounds were found. However, there are disadvantages to WDRC in amplifying impulse sounds. While WDRC systems differ in their specific characteristics, none have dynamic characteristics that are fast enough to keep up with the rapid onset of impulse sounds. This means that when an impulse sound occurs, the gain provided during the first milliseconds of the impulse noise will be the same as the gain for sounds the moment before the impulse occurred. Perceptually, this brief overshoot in gain might result in an experience like that mentioned previously, where a spoon dropping on a hard surface can sound quite disturbing.

To avoid this issue for users who are bothered by impulse noises, ReSound Impulse Noise Reduction can detect impulse sounds and instantly reduce them. It differs from other impulse noise reduction algorithms in the following important ways that help to preserve the natural quality of the sound and the audibility of speech.

1. Detection according to environmentally dependent rise time thresholds

Impulse sounds are detected based on their fast increases in level, known as rise times. In quiet situations, the detection threshold for the rise time must be high in order to prevent false detections of low level desired impulse sounds, such as speech sounds. However, when the environment is noisy, there is less headroom for dynamic change. If the rise time threshold is higher, it will be difficult for the system to detect impulse sounds. Therefore, the threshold needs to be high in quiet environments, and lower in noisier environments. ReSound Impulse Noise Reduction uses information from the environmental classifier to adaptively adjust the rise time criterion in order to accurately detect impulse sounds in many different types of environments.

2. Frequency and environmentally dependent gain reduction

Most impulse noise reduction features apply a broadband reduction in gain, which can affect the naturalness of the sound. ReSound Impulse Noise Reduction calculates an individualized gain reduction function that aims to preserve loudness according to the gain prescription. This calculation is based on the overall level of the input sound and the frequency dependent gain prescription for the individual. As illustrated in Figure 1, the gain reduction for an impulse sound will be less when the overall input level is low (in quiet situations) than when it is high (in noisy situations).

3. Scalability for personalisation

Individuals experience impulse sounds through their hearing aids in different ways. Some users are not really bothered by impulse sounds, some are only bothered by very loud impulse sounds, and still others are sensitive to less loud impulses like crumpling paper

or a clicking keyboard. For this reason, ReSound Impulse Noise Reduction can be set to a level that corresponds to the individual's sensitivity to impulse sounds. The Mild, Medium and Strong settings map to decreasing broadband power levels (shown on the y-axis of Figure 1 for the Mild setting strength) and result in the algorithm being more sensitive to quieter inputs for stronger settings.

Figure 2 illustrates how ReSound Impulse Noise Reduction can affect the signal acoustically. 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. But what is the perceptual effect of ReSound Impulse Noise Reduction? Two studies carried out by ReSound's research lab illustrate how users can benefit.

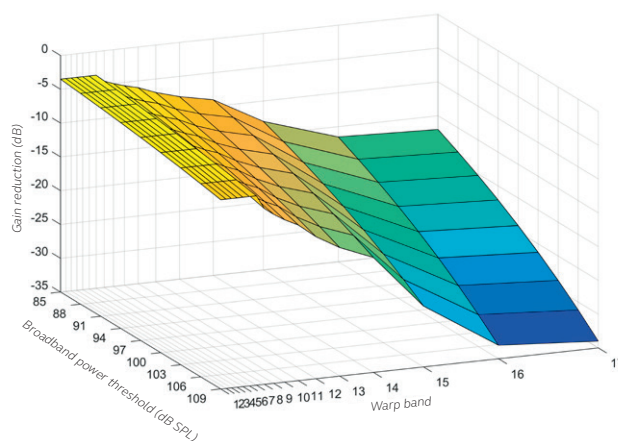


Figure 1. This example shows the gain reduction function for impulse sounds for a particular audiogram and the Mild setting. The individual calculation depends on the gain prescription, the environment, and the Impulse Noise Reduction setting.

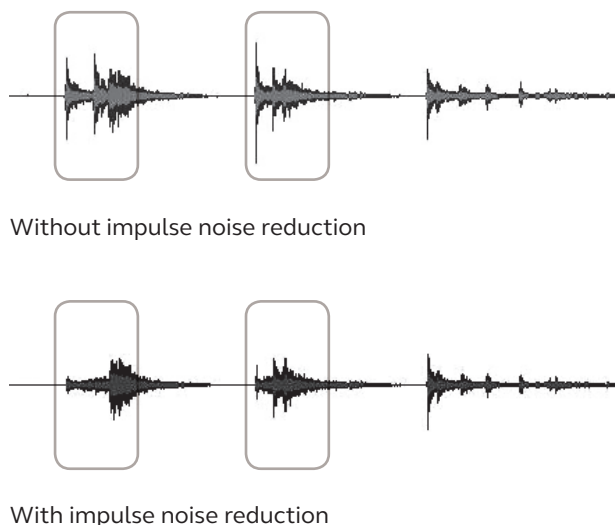


Figure 2. Impulse noise reduction works in parallel with the Warp compression system to ensure that transient sounds are not overamplified. Soft transient speech sounds are preserved. In this example, the sound of plates being stacked was recorded through a ReSound LiNX Quattro hearing aid with (bottom panel) and without (top panel) impulse noise reduction active. The boxes show how peaks where overshoot occurs are reduced with impulse noise reduction.

PERCEPTUAL RESULTS WITH RESOUND IMPULSE NOISE REDUCTION

Hearing aid users participated in a laboratory listening test to investigate the effects of ReSound Impulse Noise Reduction. In addition, participants in a field trial that was carried out as part of the development process for ReSound LiNX Quattro were fit with the ReSound Impulse Noise Reduction algorithm on the Mild setting as a default.

Subjects

Eleven experienced hearing aid users with mild to severe hearing loss (Figure 3) participated.

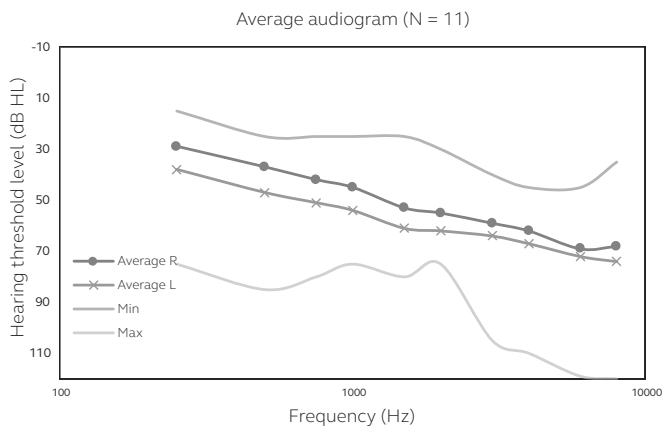


Figure 3. Average audiogram with maximum and minimum thresholds.

Stimuli

Testing was conducted with recorded and live sounds as listed in Table 1 along with their peak levels. All were impulse sounds. The “Emptying dishwasher” sound included impulse sounds at irregular intervals whereas the others included impulse sounds at a more regular and predictable rate. Recorded sounds were tested with the impulse noise reduction (INR) set to Strong and to Mild.

Participants also listened to live sounds with INR off and on. The live sounds were produced by the investigator and included: clicking a pen, placing a cup on saucer, banging a fork on a plate, dropping keys on a wooden table, ringing of a reception bell, placing a pot on a table and placing a lid on a pot. Live sounds were tested with the INR strong setting only to ensure the participants would be likely to perceive a difference. In addition, the Strong setting was meant to simulate a “worst-case” scenario for sound quality, as there is a higher risk for more aggressive signal processing to produce unnatural sound.

Method

Subjects were fit with ReSound LiNX Quattro hearing instruments. Gain was set based on audiometric thresholds, and used Audiogram+ default settings. Loudness discomfort levels were tested at 500 and 2000 Hz to verify that MPO settings did not exceed these levels.

Recorded sounds were looped for the presentation and the participant could toggle back-and-forth between hearing aid programs with and without INR active using a remote control. Participants did not know which program had INR active. This listening test was performed once with a Mild setting of INR and once with a Strong setting of INR.

The investigator produced the live sounds described above with a few seconds between presentations. After three presentations of each live sound, the participant was asked to switch to the other program via the remote control. Common to both the recorded sounds test and the live sounds test was that participants were asked if they could hear a difference between the two programs in the hearing aids. For the recorded sound, the participants were asked to indicate which of the programs was louder in cases where a difference was perceived. For live sounds participants were also asked which program they preferred in cases where a difference was perceived.

Recorded sounds	Recorded peak level
Knife on bottle	92 dB SPL
Hammer on Nail	117 dB SPL
Applause	114 dB SPL
Hammer on Wood	116 dB SPL
Bottle on bottle	101 dB SPL
Emptying dishwasher	104 dB SPL

Table 1. Recorded sounds and peak levels measured at ear level.

Results

For the testing with the recorded sounds listed in Table 1, participants could hear a difference between INR off and INR on when INR was set to Strong in 89% of the total comparisons for the impulse sounds and people were 100% correct in judging the sound to be softer with INR on. For “Emptying the dishwasher”, only 45% of the participants could detect a difference between INR off and on. This is likely due to this signal varying more. The other signals such as “Hammer on nail” were more repetitive and thus it was likely easier to hear differences between INR on and off. This may indicate that in real life where most sounds are variable, INR will turn sounds down, but the changes will not be very noticeable to most people. When INR was set to Mild, all participants heard a difference between INR off and INR on for at least some sounds. In 71% of trials participants reported hearing a difference between INR on and INR off and in 68% of trials they picked INR on as sounding softer.

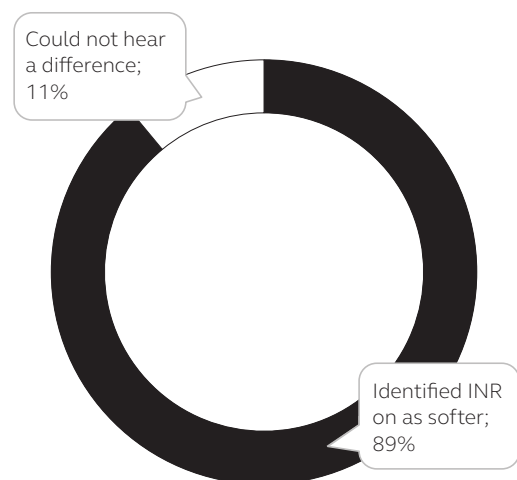


Figure 4. For the recorded impulse sounds, all participants could hear the difference between INR off and on at the strong setting for at least some sounds, and in all cases where a difference was heard, listeners judged INR on as softer than INR off.

When testing with live sounds and INR set to Strong, most participants could perceive a difference between INR on versus INR off. Not surprisingly, listeners were most likely to hear a difference between INR on and off for the loudest sounds presented. The difference in preferences for INR on versus INR off may correspond with how loud the sound was perceived. For the softest live stimuli such as a pen clicking, those who could perceive the difference, preferred the INR setting to be off. Because results with the recorded sounds showed that fewer than half of participants detected whether INR was off or on with the Mild setting, it is likely that those who did not prefer the sound of the pen clicking with Strong might not have perceived a difference between off and the Mild setting.

Taken together, the results of the listening test with live and recorded sounds support that while INR effectively reduces loud impulse sound in most real-life situations it will not be readily discernable and thus will not disrupt sound quality for hearing aid users. The Strong setting, which affects both loud and less-loud impulse sounds reduces sound more than the Mild setting as evidenced by the fact that participants could discern the effect of INR strong in a greater proportion of trials. For impulse sounds that are moderate or low in loudness, such as the pen-clicking in the current test, results suggest that users may prefer a Mild setting as these sounds are not uncomfortably loud and a mild setting will preserve the most authentic sound.

Field trial results

As part of the hearing aid development process at ReSound, field trials are conducted in order to validate usability and benefit in actual use. The final field trial for ReSound LiNX Quattro, which was the first product to include Impulse Noise Reduction, had 35 adult participants with hearing losses ranging from mild to severe. Thirty of them were experienced hearing aid users. They were fit with ReSound LiNX Quattro RIE hearing aids and wore them in their daily lives for six weeks. INR was activated on Mild per recommended default settings, and was not systematically changed during the trial period. This is because such trials are not experimental, but are intended to ensure that performance of the product meets expectations in the intended use conditions. After six weeks of wear time, no participants expressed complaints related to annoyance of impulse noises, nor were there complaints reported that would be consistent with overactivation of INR or unnatural sound quality due to INR.

Participants also completed purpose-built questionnaires where they rated their experience with the hearing aids on different dimensions. Loudness of the sound and sound quality are the dimensions where INR might be expected to affect results. Figure 4 shows the percentages of participants who chose “Strongly agree” or “Agree” to the statements related to loudness and sound quality. The responses did not reveal issues that might be attributed either to ineffective or overly aggressive impulse noise reduction. Taken together with the more specific lab test data, these results suggest that ReSound Impulse Noise Reduction can be a contributor to listening comfort without detracting from the overall sound quality, loudness and audibility provided by the hearing aids.

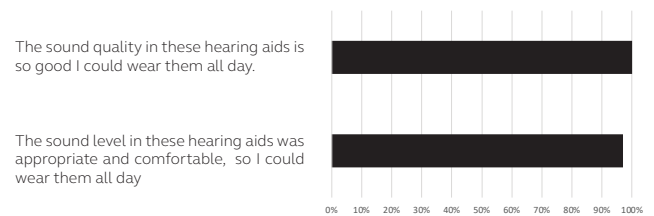


Figure 5. The percentage of participants in the field trial who responded “Strongly agree” or “Agree” with statements on loudness and sound quality.

SUMMARY

Although WDRC and noise management features have helped the commonly reported issue that hearing aids can make loud sounds too loud, there are types of noises that are not made better. Impulse sounds can be overamplified by WDRC hearing aids to the point of annoying the user. ReSound Impulse Noise Reduction was introduced to address annoyance associated with impulse noise without affecting the overall loudness and sound quality of the hearing aids. It is unique from other impulse noise reduction algorithms in that it uses environmental information to more accurately identify impulse sounds in different acoustic conditions. It also applies a frequency dependent gain reduction function based on the individual’s gain prescription and the identified environmental conditions. Finally, it is important that ReSound Impulse Noise can be personalized for the individual user, as reactions to impulse sounds as heard through the hearing aids can vary significantly among people. Results from lab listening tests and an at-home trial suggest that this feature can be helpful in ensuring the most comfortable sound without adverse effects on sound quality. Nearly all test participants could detect and preferred the amplified sound of impulse noises with ReSound Impulse Noise Reduction activated for loud sounds, and a larger group of test participants indicated loudness levels and sound quality that allowed them to enjoy wearing the hearing aids all day long.

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