REXTON REACH
EVERY VOICE MATTERS

WHITE PAPER

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APRIL 2023

REXTON

INTRODUCTION

So much of our daily life depends on communication. In a very basic form, this can be a one-to-one conversation between two people. And in an ideal listening environment, this is a conversation in a well-lit room between two people facing one another and without any notable background noise. However, we know that daily life is much more complicated than that. Important speech information may be mixed with a variety of background sounds. And the important speech we need to hear does not always come from one talker, but rather, from multiple speakers in multiple locations. And all of the added environmental complexity does nothing to make the speech message…or messages….less important. In these cases, we depend on our hearing to help us reach out to those with whom we are communicating because every voice matters.

Rexton Reach is designed specifically to help provide the confidence and reliability the hearing aid user needs in these dynamic listening situations. Reach builds on the processing strength of its predecessor BiCore with its unique Speech Preservation Technology (SPT). As shown in Figure 1, BiCore with SPT separates focus speech in the front hemisphere from surrounding sounds and processes both sets of signals independently of one another. With this unique processing approach, BiCore technology provides robust performance in some of the most challenging listening situations. Rexton Reach stretches beyond those achievements to address even more challenging communication demands.

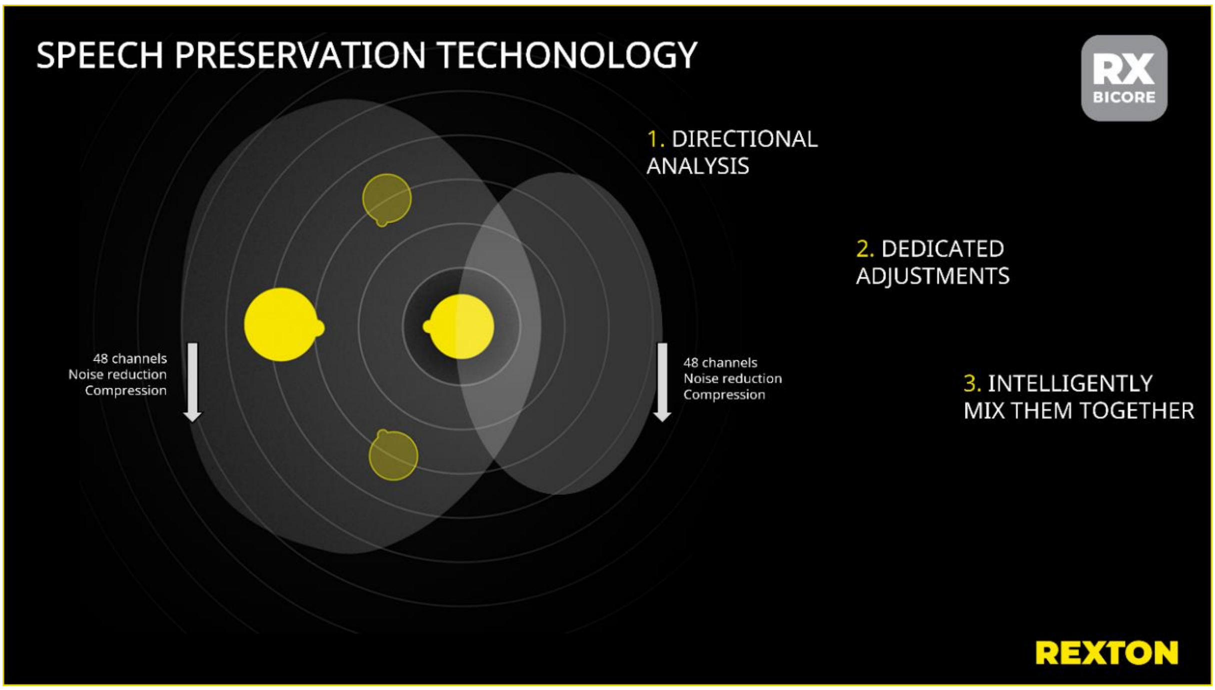

Figure 1. Illustration of Rexton Speech Preservation Technology and speech processing steps.

Speech understanding in noise is a common challenge for hearing aid users (Picou, 2022). We often visualize it as a scenario where two people (the hearing aid user and their conversation partner) are speaking together in a noisy background. In these scenarios, directional microphone technology has been repeatedly shown to provide improvements in the signal-to-noise-ratio (SNR) to help with speech understanding in noise. Additionally, as noise levels increase, binaural beamformers such as Stereo iLock provide additional SNR benefit by narrowing the focus to the target speaker and reducing the interference of noise. This becomes an ideal approach for a one-to-one conversation in noise. However, despite that being a regular occurrence, it is also important to consider situations with multiple speakers.

When we think about multiple-speaker scenarios, we can picture a group of friends at a café having an active discussion. Or maybe we can picture someone in the food-service industry talking with different customers from different directions while there is activity coming from the rear direction. Or maybe a parent talking with children at a busy playground. In all of these situations, it is unrealistic to think everyone is taking turns talking to the hearing aid user and allowing ample time for the hearing aid user to face the speaker. In this case, although a narrow directional beam will highlight the speaker, other comments or the initial change in speakers will be missed. Conversely, if we allow the directionality to be too lax (more omnidirectional) then competing noise from all angles will begin to interfere and impede the audibility of the speech signal. In these cases, a directional system that can adapt for multiple speakers is required.

The Rexton Reach platform provides just such an adaptive directional microphone system. Reach seamlessly adapts to multiple speakers with an adaptive four focus beam directional system to ensure optimal audibility in sub-optimal listening conditions. This effective multi-beam system builds on proven Rexton technology and introduces three new technology pillars.

TECHNOLOGY PILLARS

Rexton Reach is supported by three new technology pillars (Figure 2) to help users in these challenging listening situations: Multi-Voice Focus, Voice Stabilizer, and Connectivity. These pillars build on those introduced with BiCore technology. BiCore was designed around the pillars of Reliable Technology, ClearSound and Lifeproof. Nothing is sacrificed with the design of the Reach platform. Moreover, the new technology pillars in Reach further expand the dependability of the Reliable Technology.

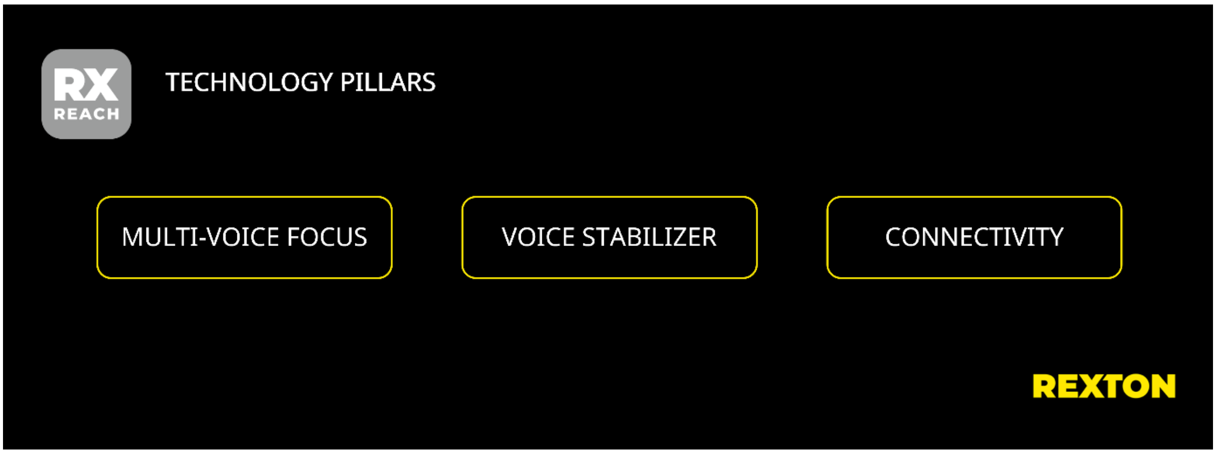

Figure 2. Rexton Reach platform technology pillars of Multi-voice Focus, Voice Stabilizer and Connectivity.

MULTI-VOICE FOCUS

Multi-Voice Focus (MVF) opens up new opportunities for conversations with multiple speakers. Multi-Voice Focus builds on the Speech Preservation Technology (SPT) introduced with BiCore (see BiCore whitepaper, 2021, for more details). As mentioned, BiCore introduced SPT. SPT separates target signals such as speech from surrounding noise signals and processes the resulting focus beams independently. Reach with MVF builds on SPT and enhances reliability by simultaneously steering not just a frontal and rear focus beam, but four independent focus beams for the speakers while continuously analyzing the listening scene (Figure 3).

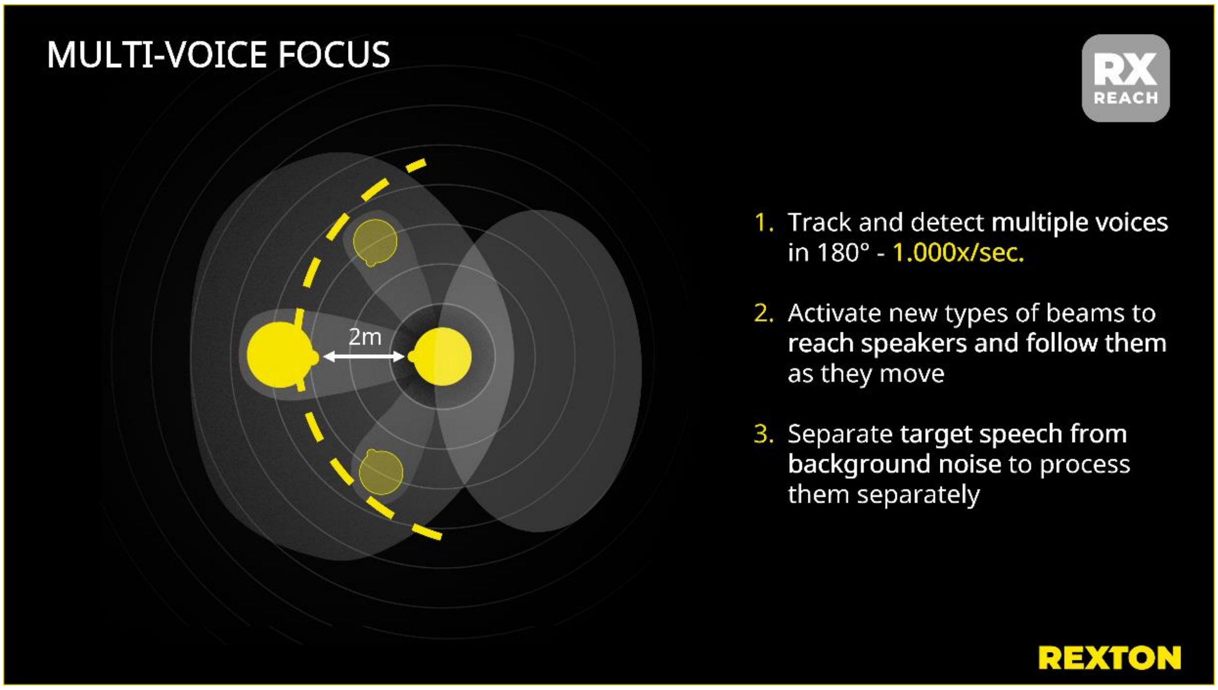

Figure 3. Multi-Voice Focus with four focus beams.

In a multi-speaker situation, the SPT identifies the speakers in the front as well as surrounding sounds which are most commonly non-speech sounds. Each beam incorporates processing features such as dynamic noise reduction and compression characteristics separately in each of 48 channels, providing discreet and focused signal processing. MVF provides a directional analysis scanning the surrounding environment 1000 times per second to identify the speakers and generate multiple focus beams. Each beam or region has individual, dedicated adjustments to follow and maintain speech in the respective focus stream. With the continuous analysis of the listening environment, the beams can track speakers even as they move. The signals are intelligently mixed together along with the processed surrounding sounds.

SoundPro 3.0 combines traditional speech in noise processing with the innovations introduced with BiCore and the introduction of MVF processing to help in advanced speaker detection. This layered processing is further enhanced by wireless communication between devices. With wireless communication, each device can incorporate processing from the device on the opposite ear to generate a more complete overview of the listening environment and speakers.

Multi-Voice Focus is a key component of complex engine of SoundPro 3.0 for the Reach platform. Introducing four focus streams for independent directional processing of the listening environment generates another tool in Rexton's proven portfolio of technology to reliably manage the variety of difficult listening situations. And MVF is only one of the technology pillars driving the Reach platform.

VOICE STABILIZER

Rexton Reach continues in the tradition of building on proven technology. The earlier generation of Rexton QuadCore introduced the Voice Ranger to help emphasize speech in the presence of background noise. Speech and noise can both be processed differently through noise reduction and compression techniques to help focus on the speech signal. And these processing algorithms are now further enhanced and implemented in the Reach Voice Stabilizer.

Voice Stabilizer can apply more appropriate compression and noise reduction when processing a speech signal in noise. Additionally, it can do this within each of the distinct multiple streams generated by MVF. For noise-dominated streams, noise reduction and more aggressive compression characteristics are applied to reduce distracting and unwanted signals. For speech in each of the respective beams, more linear processing is implemented to ensure that the nuances of the speech signal are preserved and that each voice gets the processing attention it deserves. By processing speech and noise differently for greater contrast within each of the beams, Voice Stabilizer can help improve the SNR for the user, thus assisting in speech understanding in noise.

Reach takes full advantage of its processing power by applying Voice Stabilizer to help enhance audibility of the speech signal and furthermore applying this in each focus beam of MVF. With these two technology pillars working in conjunction with one another, the user can approach even the most complex listening situations with confidence.

CONNECTIVITY

In today's world, there is continual growth in communication via connectivity. Although the versatility of mobile phones has expanded dramatically, a core use remains that of staying connected with friends and family. Rexton Reach approaches this aspect of connectivity as another core technology.

The Reach platform is equipped with Made for iPhone (MFI) and Audio Streaming for Hearing Aids (ASHA) protocols. The protocols help the Reach device interact with the mobile phones for seamless connecting and optimal communication with the device. This means the user can appreciate phone calls and audio streaming with personal devices, even via hands-free use with supporting devices.

Reach also is future-proof. With growth in Bluetooth Low Energy (BT LE), Reach is prepared for advances in BT LE audio. As newer technologies come to market, Reach is prepared to interact with these approaches via simple firmware updates to always stay on top of the user's needs.

In summary, the three core pillars of Multi-Voice Focus, Voice Stabilizer and Connectivity work together to make Rexton Reach the dependable solution users expect as they face life's variety of listening situations.

RESEARCH SUPPORT

Rexton is built on reliable, proven technology. To that end, the Reach platform was not only evaluated internally during the development process, but also through research studies. In this section we would like to review research support for Reach platform looking at three key studies.

STUDY 1: IMPROVEMENT IN OUTPUT SNR

The first study evaluates the expected improvement in output SNR provided by MVF and Voice Stabilizer. Laboratory measures were conducted to determine changes in the SNR of speech-in-noise signals via the Reach platform processing. Adaptive features such as feedback cancellation and frequency compression were deactivated to prevent interference with the measurement method.

As shown in Figure 4, a KEMAR manikin was positioned in central position in a sound treated room one meter from all loudspeakers used for the experiment. Target signals comprised of the International Speech Test Signal (ISTS) (Holube et al., 2010) were presented alternately from 0° and 315° azimuth at approximately 76 dBA. Background noise consisting of busy cafeteria noise mixed with pink noise was presented at 135° and 225° azimuths at a level of around 72 dBA.

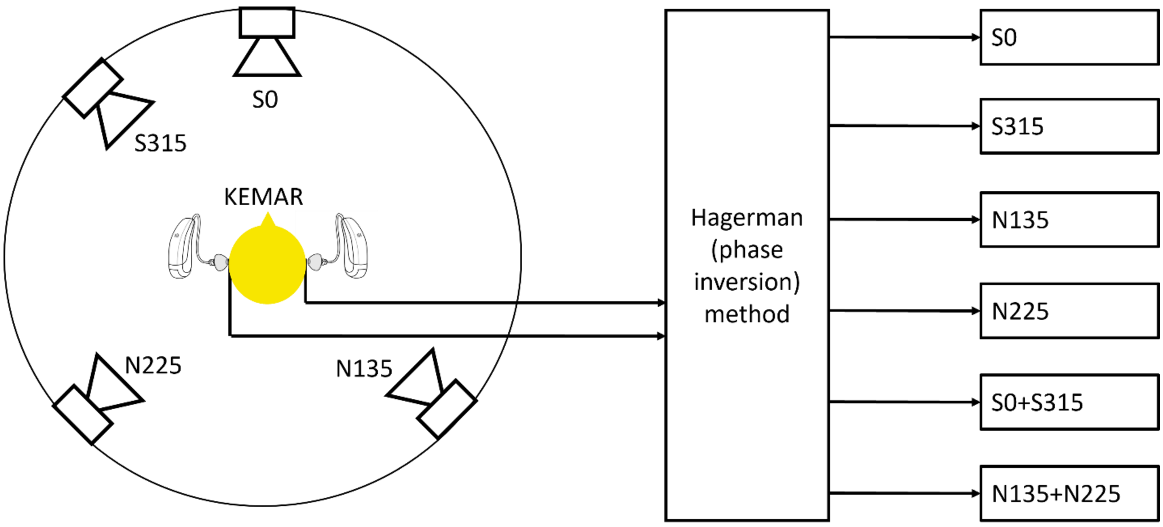

Figure 4. Setup used for output SNR measurements. Speech (S) signals were presented alternately from the two loudspeakers in the front hemisphere, and noise (N) signals were presented from the two loudspeakers in the back hemisphere. The signals processed by the hearing aids were recorded in the KEMAR ears, with and without phase inversion of each signal, and the Hagerman method was used to generate estimates of the various S and N signals, both alone and in combination.

Premium technology level receiver-in-canal (RIC) devices on the Reach platform were used for the investigation. The hearing aids were programmed to a flat 50 dB HL hearing loss using the proprietary fitting algorithm. Measurements were done with the devices placed on the KEMAR manikin ears as well as in the unaided condition.

Measurements were conducted using the Hagerman phase-inversion technique (Hagerman and Olofsson, 2004) and in alignment with the version incorporated by Aubreville and

Petrauch (2015). This approach is used to assess noise reduction processing when a combined speech and noise signal is presented to the hearing aids. The technique is built on the condition that two identical signals presented 180° out of phase from one another will cancel each other out when the signals are summed. To assess the noise reduction system, the speech in noise signal is recorded twice. For the second recording, the noise signal is inverted by 180° so that when the recordings are combined, the noise signals are cancelled out, leaving only the clean speech signal. The output recordings of both the processed "clean" speech and the processed noise can be analyzed to determine the SNR result from the hearing aid.

The speech and noise signals were presented to the hearing aids for 50 seconds to allow any of the adaptive processing of the devices to stabilize before recordings were completed. The ISTS signal was presented in alternating 10 second intervals from the front two speakers while the noise signal was presented continuously from the rear speakers. The 10 second intervals were repeated for a total of two 10-second presentations for each speaker. See Figure 5 for an illustration of the recording setup.

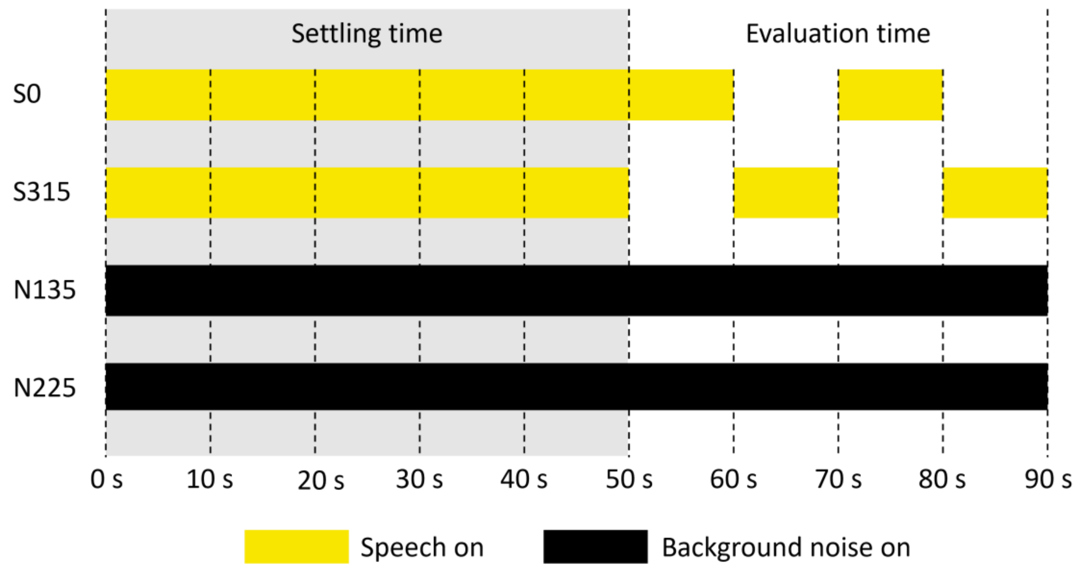

Figure 5. Presentation of input signals from the four loudspeakers. The signal presentation started at t=0, while recordings used for the analysis were started at t=50 seconds to allow enough time for the hearing aids to reach a stable working condition. The analysis was based on 40 seconds of recordings (evaluation time), including two sections of 10 seconds from each of the two speaker locations (S0 and S315). This setup simulates the turn-taking of two speakers in the frontal hemisphere of the user with continuous noise originating from the rear/lateral hemisphere.

For analysis purposes, the output from the left hearing aid was used for recordings and measurements as it provided the "better" ear effect due to proximity to both speakers. The SNR results were determined for the front and side ISTS speakers separately and then averaged together.

The overall output SNR of the Reach platform using MVF with Voice stabilizer was 11.8 dB (Figure 6). This result was nearly 8 dB over that of the unaided (open) KEMAR condition.

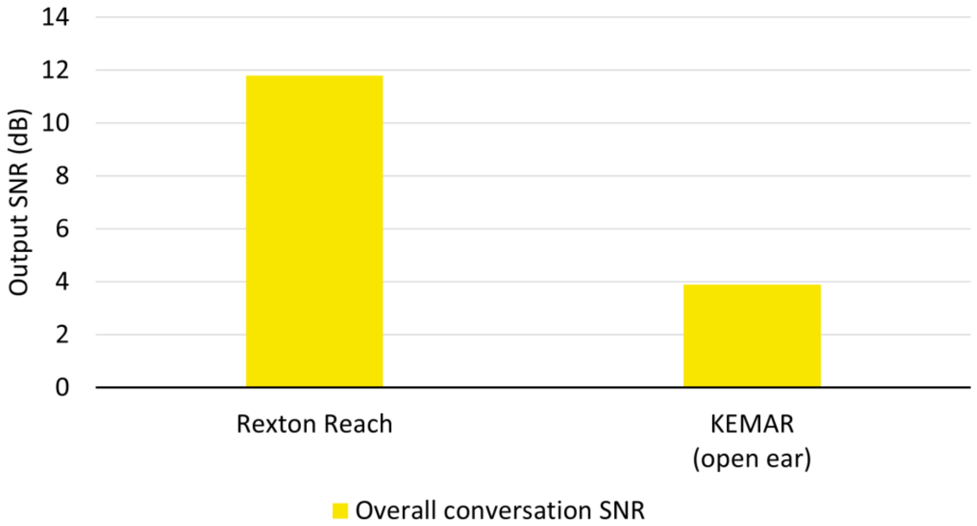

Figure 6. Overall conversation output SNR across the two speaker locations, for Rexton Reach and for the unaided (open ear) KEMAR.

The output SNRs for the frontal and lateral speakers is shown in Figure 7. The output SNR for the 0° speaker was 9.9 dB which was 8.9 dB higher than the open ear condition. The output SNR for the lateral (315°) speaker was 13.3 dB which was 7.5 dB higher than the open ear SNR. It is important to note that the open ear differences between the front and lateral positions were affected by the directional characteristics of the open ear, torso effects, acoustics of the measurement room, and the relative position of the loudspeaker.

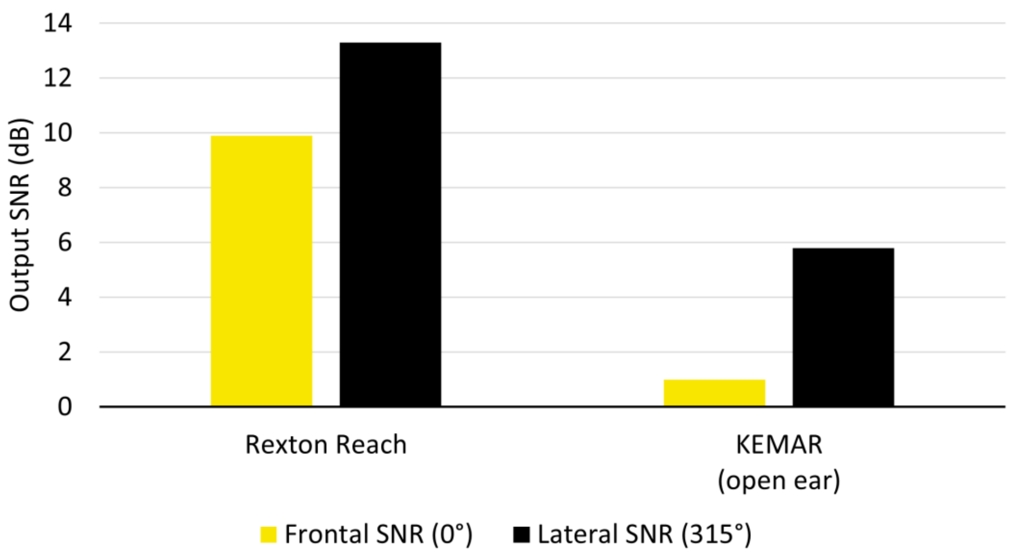

Figure 7. Output SNRs for the frontal and lateral speaker locations, respectively, for Rexton Reach and for the unaided (open ear) KEMAR.

The results from the SNR study indicate that users can expect a considerable improvement on the SNR from the Rexton Reach. The combined features of Multi-Voice Focus and Voice Stabilizer support the philosophy that every voice matters.

STUDY 2: IMPROVED SPEECH UNDERSTANDING IN NOISE WITH MVF AND VOICE STABILIZER

The previous study illustrates that the Reach platform can provide an improved output SNR. A second study investigating the benefits of Rexton Reach was designed to look at user performance wearing the devices.

Twenty experienced hearing aid users (10 male and 10 female) with an age range of 55 to 82 years (mean age:72 years) participated in the study. The hearing loss was a sensorineural, sloping bilaterally (see Figure 8 for mean audiogram). All participants were experienced hearing aid users.

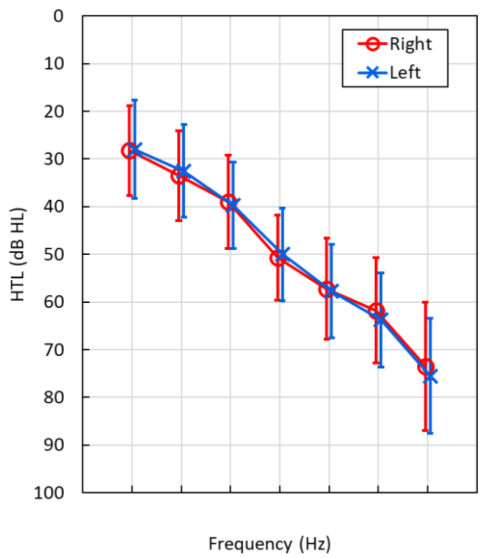

Figure 8. Mean audiogram for left and right ears of the 20 participants. Error bars indicate ± one standard deviation.

The devices were premium RIC style hearing aids programmed to the proprietary fitting algorithm for experienced users. Half of the participants used closed sleeves while the other half used vented sleeves. The instruments were programmed with two programs. The first program included all of the Reach platform features such as MVF active. The second program was designed with MVF deactivated. However, the SPT processing remained activated.

Participants were asked to complete separate speech in noise tasks. The first speech task was the traditional implementation of the German Matrix test, the Oldenburger Satztest (OLSA; Wagener et al., 1999). In this test, the participant was seated in a test room with speakers positioned at a distance of 1.3 meters at the 0° and 180° azimuths. The participant was asked to repeat speech sentences presented from directly in front while a non-modulated speech-shaped noise was presented from the rear speaker at 65 dBA. The target speech sentence level varied in an adaptive manner depending on correct and incorrect words in the sentence. The goal was to identify the SNR at which the participant achieved a speech reception threshold of 80% (SRT80).

The second speech test was also based on the OLSA, however, the test was modified to simulate a multi-speaker scenario. The room used was a meeting room style with some reverberance. Two front loudspeakers were positioned at 20° and 340° azimuths, 1.5 meters from the participant, to simulate two separate speakers. Participants were not restricted in head movement, so they could turn towards a given loudspeaker if they desired, as they would during normal conversation. Masking noise was presented from five separate loudspeakers positioned 2.5 meters from the participant. The speakers were placed at 90°, 135°, 180°, 225° and 270° azimuths (see Figure 9 for setup). The masking noise was comprised of the same sentences used for the target speech; however, the sentences were presented continuously and uncorrelated at a fixed level of 67.5 dBA. The task again was to repeat the sentences to determine the SRT80.

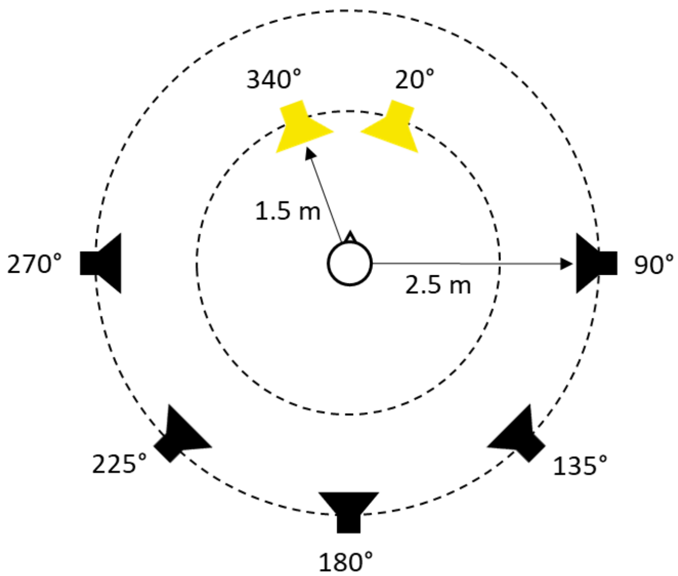

Figure 9. Loudspeaker setup used in the modified OLSA test, simulating a group conversation scenario. Target sentences were presented alternately from the two yellow loudspeakers, while masking sentences (babble noise) were presented from the black loudspeakers.

RESULTS

The results for the traditional OLSA indicated lower (better) SNRs for the SRT80 with the MVF feature activated as compared to deactivated (Figure 10). With the feature activated, the mean SRT80 was -8.8 dB as compared to -7.2 dB with the feature off. Additionally, when results were analyzed to determine benefit on an individual level, 90% of the participants demonstrated an SNR benefit from the MVF.

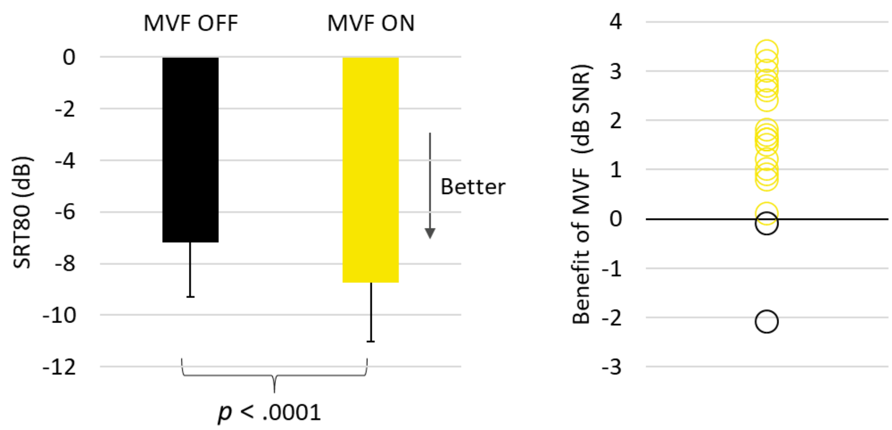

Figure 10. Left plot: Mean SRT80 for MVF OFF and ON, across 20 participants in the standard OLSA test. Error bars indicate one standard deviation. Right plot: The individual SRT80 differences between MVF OFF and ON. Yellow circles show positive differences, indicating an SNR benefit provided by MVF.

Statistical analysis with a repeated measures ANOVA with SRT80 as the dependent variable, HA setting (MVF OFF/ON) as an independent variable, and with coupling (closed/vented) as a categorical factor. The analysis showed a significant effect of HA setting ($F(1, 18) = 27.76$, $p < .0001$) and a significant effect of coupling ($F(1, 18) = 5.38$, $p < .05$). There was no significant interaction between HA setting and coupling ($F(1, 18) = .0003$, n.s.). Thus, even though the group with closed couplings outperformed the group with vented couplings, the SNR benefit provided by MVF was the same for both coupling groups. Furthermore, a Tukey HSD post-hoc test confirmed that the benefit from the MVF was significant in both subgroups ($p < .01$). In summary, the analysis showed a clear and statistically significant benefit of MVF for the standard OLSA test.

For the modified OLSA with the simulated multi-speaker scenario, results (see Figure 10) indicated a 1.1 dB mean benefit of the MVF activated (-3.6 dB) over the deactivated condition (-2.5 dB). Additionally, on an individual level, 95% of the participants showed benefit with the MVF activated.

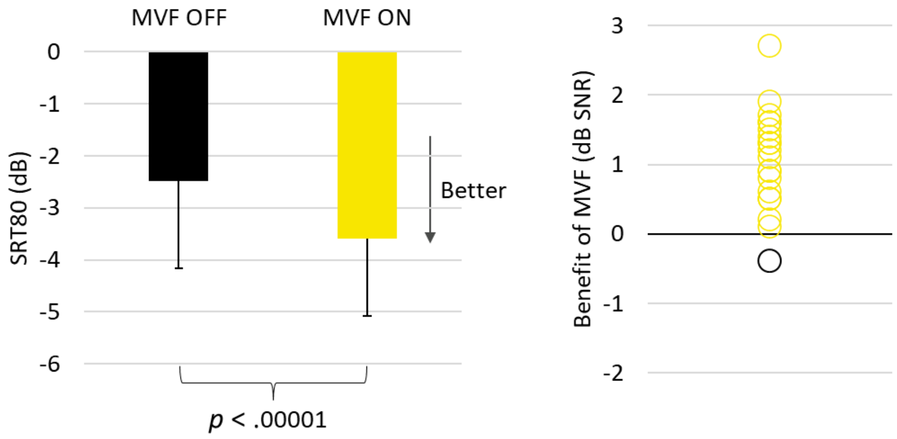

Figure 11. Left plot: Mean SRT80 for MVF OFF and ON, across 20 participants in the modified OLSA test simulating a group conversation. Error bars indicate one standard deviation. Right plot: The individual SRT80 differences between MVF OFF and ON. Red circles show positive differences, indicating an SNR benefit provided by MVF.

Statistical analysis using a repeated measures ANOVA showed a highly significant effect of HA setting of MVF on/off ($F(1, 18) = 43.16$, $p < .00001$), but no significant effect of the vented/closed coupling ($F(1, 18) = 0.051$, n.s.) and no significant interaction between those same settings and couplings ($F(1, 18) = .060$, n.s.). Thus, in this test, the two subgroups performed at the same level and experienced the same SNR benefit from the MVF. A Tukey HSD post-hoc test showed that the MVF being activated was statistically significant for both subgroups ($p < .01$). In summary, the results from the modified OLSA test also showed a clear and highly significant benefit of MVF in the simulated group conversation.

For both test measures (traditional OLSA and modified OLSA), Rexton Reach demonstrated a significant improvement in SNR with MVF activated when compared to the feature deactivated. Additionally, it is expected that these benefits would carry over to user experiences in real world listening situations.

STUDY 3: REAL WORLD BENEFIT

The final study for the Reach platform was to investigate real world satisfaction with the technology. Considering the lab measures showing an improvement in SNR as well as the controlled study results indicating improved performance on speech-in-noise testing, the next step in evaluating the effectiveness of the new processing was direct user reports.

Respondents were surveyed in the United States, Germany, Taiwan, the United Kingdom, Australia and Italy. The 78 respondents included 31 females and 47 males between the ages of 20 and 89 years old (average: 64 years). The respondents were all experienced hearing aid users and had mild-to-moderate sensorineural hearing loss. They were wearing fitted bilaterally fitted hearing aids of different makes and models with an average age of ownership of 4 years. The questionnaires were administered via online surveys through email and text messages.

All respondents were fitted bilaterally with premium RIC products with M receivers from the Reach platform. Sleeves (closed or vented) were selected as deemed appropriate for the hearing loss by their respective hearing care provider (HCP). The proprietary fitting rationale was used; however, the HCP could make adjustments as deemed necessary for the fitting.

Respondents followed a specific wearing protocol between the new devices and their own devices along with completing the survey questionnaires. Prior to being fitted with the new hearing aids they were asked to complete the survey questionnaires. They were then fitted with the new devices and asked to wear them for a three-week period. At the end of three weeks, they again completed a questionnaire. At this time, the respondents were asked to change back to their own, previous hearing aids and wear them for a two-week period. At the end of that two-week period they were again asked to complete a questionnaire and switch back to the new devices. After another two-week period, the respondents completed the final questionnaire. All questionnaires were the same except for the final questionnaire which included additional questions pertinent to the experiences with both pairs of devices.

The questionnaires consisted of questions about the user’s listening experience with the devices as well as satisfaction questions. Both categories consistent of multiple questions built around a 7-point Likert-scale. The response options were provided based on the wording of the question. One group of response options was:

“very unsatisfied,” “unsatisfied,” “somewhat unsatisfied,” “neutral (neither satisfied not unsatisfied),” “somewhat satisfied,” “satisfied” and “very satisfied”

The second group of response options was:

“strongly disagree,” “disagree,” “somewhat disagree,” “neutral (neither agree nor disagree),” “somewhat agree,” “agree” and “strongly agree.”

A third category of questions included only “yes/no” or a selection of the new device or the previous device.

RESULTS

The results presented are based on responses to the questionnaires completed after the second wearing of each pair of devices.

On the questions regarding satisfaction, positive satisfaction was determined to be responses of "somewhat satisfied," "satisfied," or "very satisfied." As shown in Figure 12, the Reach platform outperformed the respondents' existing hearing aids in all six satisfaction categories. For overall satisfaction, 86% reported being satisfied with the new devices as compared to 58% reporting satisfaction with their own devices. Satisfaction rates for the other questions ranged from 79% to 92% for the new devices, whereas the range for the own devices was 47% to 69%. It is important to note that the highest difference between ratings was for satisfaction with speech understanding (47% for the own devices and 79% for the new devices) suggesting that the Reach technology is successfully achieving the goal of helping users understand speech in a variety of listening environments.

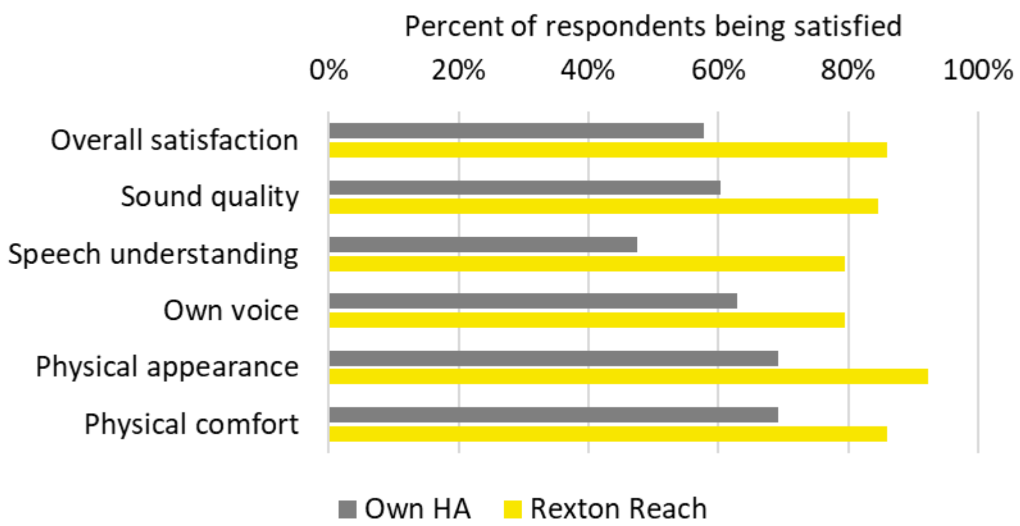

Figure 12. Percentage of respondents expressing satisfaction with own hearing aids and Rexton Reach, respectively, in each of six questions.

Statistical analysis for the satisfaction rates between the new devices and the respondents' own devices was completed with a two-proportion z-test, using a Benjamini-Hochberg correction to control for multiple comparisons. Results showed that for all six questions, the proportion of satisfied respondents was significantly higher for the Reach platform than for own hearing aids (all $p < .05$).

The second group of questions focused on the conversation experience with the Reach platform. Similar to the satisfaction ratings, as shown in Figure 13, agreement rates were all higher with the new devices than with the respondents' own devices. Responses of "somewhat agree," "agree" and "strongly agree" were used to comprise a result of agreement for the respondent. Response rates showing agreement with the respective statement when wearing the new devices ranged between 74% and 87%, whereas those for the own devices ranged from 43% to 64%. Interestingly, in response to the statement of not having to withdraw from group conversations, 82% of respondents wearing the Reach platform responded positively, as compared to only 51% with own hearing aids. This is again consistent with the goals and design of the Reach platform.

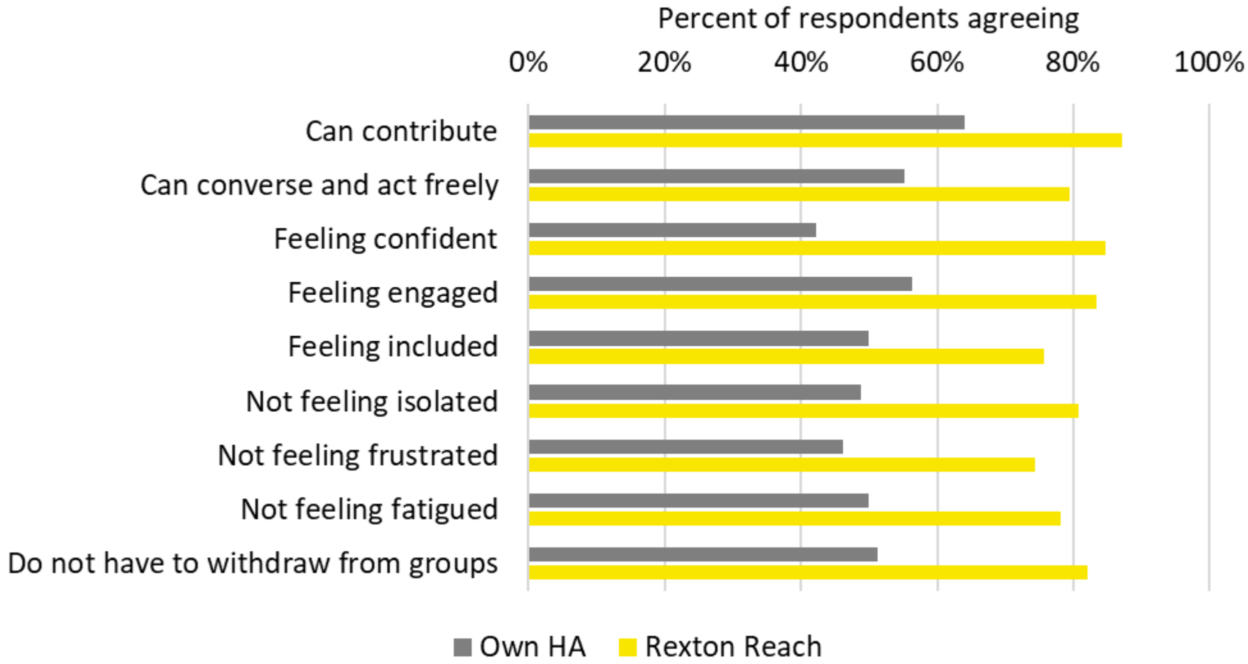

Figure 13. Percentage of respondents agreeing with each of nine different statements related to the experience of being in a conversation, when wearing their own hearing aids and Rexton Reach.

Again, for statistical analysis a two-proportion z-test with a Benjamini-Hochberg correction for multiple comparisons was applied. For all questions, the agreement rate was significantly higher for Reach platform than for own hearing aids (all $p < .01$). Again, the responses suggest that conversation benefit with the Reach platform.

For two of the questions asked only at the conclusion of all wearing trials and as part of the fourth questionnaire, respondents were asked to respond if they would recommend each pair of devices and then they were asked to indicate if they would keep each pair of devices. As show in Figure 14, 81% would recommend the new devices whereas only 69% would recommend their own devices. For statistical analysis, a two-proportion z-test showed no significant difference between the recommendation rates the two pair of devices ($p = .096$). This result is overall positive to indicate that hearing aids are helping to improve the quality of life. Importantly, when asked about keeping the devices, 78% said they would keep the new devices whereas only 48% stated they would keep their old devices. Statistical analysis for these results showed a significant difference ($p < .0001$). Again, the results of this investigation demonstrate a noticeable benefit of the Reach platform processing and its noticeable reliability in conversation.

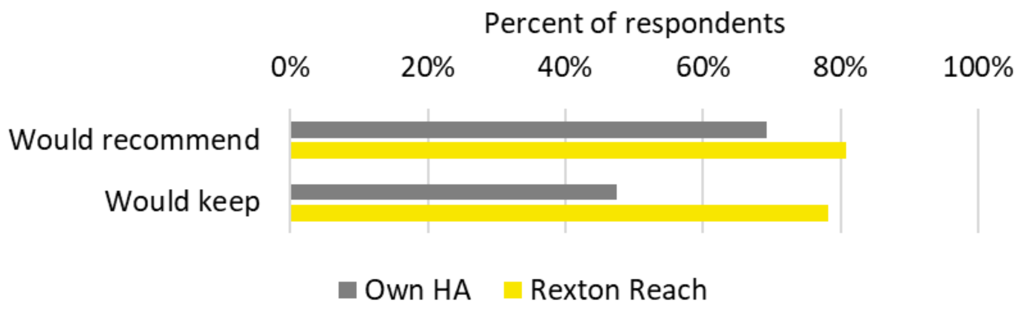

Figure 14. Percentage of respondents being willing to recommend and being willing to keep their own hearing aids and Rexton Reach, respectively.

A final set of seven questions asked at the end of the fourth wearing trial inquired on the preference of one pair of devices over the other for certain listening situations. Figure 15 shows the percentage of respondents choosing their own hearing aids and Rexton Reach respectively, for each question. Consistent with other results in the survey, the Reach platform is preferred by around 80% of respondents, whereas 20% prefer their own hearing aids. And again, consistent with other survey results, a strong preference for the Reach platform is seen with the conversation experience category, for which 82% of respondents stated that Rexton Reach performed best. These results are also comparable to those regarding the other questions about best speech understanding (79%), least listening effort (77%), most exciting listening experience (81%), feeling more energized (81%), feeling more confident (79%) and overall preference (77%). Through all seven conditions, the preference for the Reach platform is highly statistically significant according to a binomial test (all $p < .00001$).

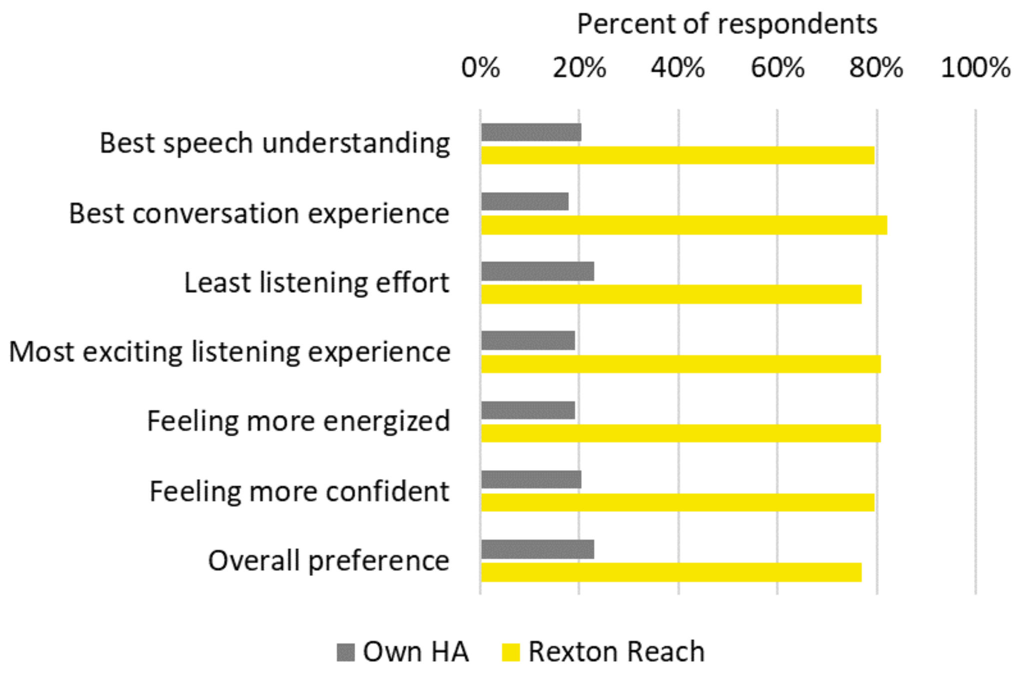

Figure 15. Percentage of respondents picking own hearing aids and Rexton Reach, respectively, when asked about which hearing aids provide the best performance in seven different perceptual and emotional domains.

RESEARCH CONCLUSIONS

All three of these studies evaluated the effectiveness of the Reach platform processing with different approaches to investigation. A technical measure revealed a clear improvement on SNR for the Reach platform. A lab study with a speech understanding in noise test with multiple loudspeakers demonstrated improved performance with the MVF active. And a field survey across multiple continents demonstrated a significant preference for the processing of the Reach platform over users' own hearing aids. Together, these results strongly suggest the Rexton Reach platform with MVF and Voice Stabilizer support the user in the goal of hearing every voice that matters.

SUMMARY

Rexton Reach is built on the philosophy that every voice matters. This holds true for communication with friends, family, coworkers, and each person with whom the hearing aid user comes into contact. With its three core technology pillars of Multi-Voice Focus, Voice

Stabilizer and Connectivity, Reach brings forward the latest innovations in hearing aid processing and builds on the strong foundation of dependable processing that is Rexton.

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