An innovative RIE with microphone in the ear lets users "hear with their own ears"

Jennifer Groth, MA, GN Hearing A/S

ABSTRACT

The Receiver-In-Ear style of hearing aids has overtaken the hearing aid market. Data from the US in 2019 indicated that almost 79% of the hearing aids dispensed were of this style. The popularity of the RIE makes sense. It is robust, comfortable, discreet to wear, and can offer the most comprehensive collection of features. A significant drawback of the RIE is that the microphones are in an unnatural location to deliver sound to the individual ear. While artificial pinna compensation algorithms mitigate this drawback to some degree, the most natural sound reaches the ear in the organic way nature intended – it is collected by the pinna. As yet another example of how the ReSound Organic Hearing philosophy inspires innovations that mimic and preserve natural hearing processes, the ReSound ONE™ RIE hearing aid can be fit with the M&RIE (Microphone & Receiver-In-Ear). This innovative receiver module places a microphone in the user's ear canal so that sound can be naturally shaped by the individual's unique anatomy, giving users all the benefits of the RIE style with the most natural sound quality.

In the US, slightly more than 10% of the population aged 50 to 59 is estimated to have mild hearing loss, with the prevalence growing to 19% for people in their 60s and 35% for older adults.[1] That is more than 22 million US adults over the age of 50 who, based on hearing loss severity, could potentially be candidates for hearing aids. Yet it is this group of people with milder hearing losses who are the least likely to adopt hearing aids. There are multiple reasons for this, but they can be captured by the idea that potential users simply don't anticipate or - for those who try them - perceive enough benefit to make hearing aids worth the cost and trouble of acquiring and using them. For people who do wear or try hearing aids, they will most likely be fit with the Receiver-In-Ear (RIE) style. In 2019, RIE made up 78.9% of the hearing aids dispensed in the US.[2] There are good reasons for the popularity of the RIE style. Hearing Care Professionals (HCPs) can have them on hand to demo or even fit them instantly with a stock dome, the style is comfortable to wear and virtually invisible on most ears, and the RIE often will have the best complement of noise management and wireless connectivity features compared to other hearing aid styles. Wireless connectivity will, in addition, probably be more robust and reliable than what is typical of custom hearing aids. Finally, there is evidence that users are happier overall with the RIE style, which is a good reason to continue to fit them. MarkeTrak 10 reported a satisfaction rate of 84% with hearing aids that sit Behind-The-Ear (most of which would be RIE) versus 79% with custom hearing aids.[3]

ARE THERE ISSUES WITH RIE?

An underlying reason that users with mild hearing loss might reject RIE hearing aids is due to sound quality that is unnatural, difficult to adjust to, and in the worst case perhaps even detrimental to their listening goals. A fundamental disadvantage of the RIE design is that the microphones which pick up the sound are located above or even behind the outer ear. This is not an advantageous location for sound quality, as it is not where sound naturally is picked up and channeled to the eardrum. The brain of an individual person expects to receive sound that has been shaped by the body, head and ear anatomy of that person. Hearing sound through a hearing aid that collects the sound in the wrong anatomical position could potentially interfere with natural hearing processes in the brain, perhaps working against the positive effects of making inaudible sounds audible. This is especially true for those with milder hearing losses because when people in this severity group are driven to seek help, it is due to difficulties hearing in noise rather than lack of audibility of everyday speech and sounds. They will most often report hearing well in many of their daily life situations. This means that their minimum expectations to hearing help would be 1) to help them hear in noise, and 2) to not degrade their hearing in any other ways. RIE hearing aids with their microphone position above the ears can go some way toward meeting the first expectation but may not fulfill the second as well as they could.

ADVANTAGES OF THE MICROPHONE IN THE EAR

With the introduction of In-The-Ear (ITE) hearing aids decades ago, considerable research effort was spent on documenting the relative advantages of hearing aid microphone placement within the ear. It was reported that microphone placement within the pinna was superior to Behind-The-Ear (BTE) microphone placement from an acoustic perspective,[4-6] and that it provided better speech recognition in noise,[6-8] as well as better ability to localize sound sources.[9] More recent investigations corroborate these findings and have added to them by examining advantages in other ways.

Cubick et al[10] demonstrated how spatial hearing abilities and speech recognition performance decreased when people listened through hearing aids that have unnatural microphone location above the ear. In their experiment, listeners with normal hearing thresholds were provided with high quality linear amplification to isolate the effects of the microphone location rather than sound processing. They suggested that the degrading effects on speech recognition in the presence of competing sounds that they observed in listeners with good hearing could have consequences for hearing aid users' ability to segregate different sounds, including multiple talkers. In other words, the very problem that might drive people with mild hearing loss to try hearing aids – hearing difficulties in situations with competing sounds – could potentially be made even worse due to microphone location.

Is spatial hearing important for people with hearing loss? Most, including both hearing aid users and non-users, do not explicitly express their difficulties or wishes in terms of perceiving sounds in space. For example, a person might say that they struggle to follow the conversation at a family gathering. But what they probably do not recognize is the role that spatial hearing plays in their ability to segregate the stream of sounds picked up by the ears to form an auditory scene and function efficiently within that scene. Byrne & Noble[11] discussed the significance of localization to hearing in real world situations, pointing out that it is such a natural part of living that it is taken for granted. It is now recognized that in real life, listeners must "locate, identify, attend to, and switch attention between signals so as to maintain communicative competence and a sense of connection with their surroundings".[12 (p86)] Results from MarkeTrak 10 do support that spatial hearing is a contributor to overall satisfaction with hearing aids. The strongest factor driving satisfaction was found to be "Hearing aid performance and sound" and a contributor to this factor was "Ability to tell direction" of sound.[13] A growing body of research is concerned with how localization cues interact with hearing in dynamic situations, and what technical aspects of hearing aids may support or work against spatial hearing ability.

As previously mentioned, it is well-established that a microphone location within the pinna is better than above it in terms of preserving the spectral filtering of the sound done by the pinna and this has been confirmed by more recent research as well.[14-16] It has also been shown that commercially available hearing aids in their default programs introduce spatial cue distortions due to both microphone location as well as sound processing features, such as adaptive directionality.[17,18]

To compensate for possible degrading effects on localization and sound quality, hearing aid manufacturers may use a pinna compensation algorithm to make up for the disadvantageous microphone location above the ear. This type of processing uses the hearing aid's two-microphone system to create spatial directivity patterns that resemble those of an average ear on an average head and torso. Improved front-back localization has been reported with pinna compensation algorithms.[19-21] While, this is good news for RIE users, pinna compensation algorithms nonetheless have two weaknesses. One is that, as mentioned, they are made for an average ear and tuned to work on an anthropomorphic mannikin. Not only will the benefit vary along with the large amount of individual variation in ear characteristics, it has also been shown that mannikins are poor stand-ins for humans when metrics for localization are considered.[16]

Another issue with pinna compensation algorithms is that they cannot account for sound coming from all azimuths and elevations. They are tuned to work for sound coming from in front on the horizontal plane. In this way, they are unlike the human ear, which will shape the incoming sound uniquely as it arrives from anywhere in the surrounding space. The importance of this in terms of monaural spectral cues is obvious, but the location of sound pickup also has a dramatic effect on the binaural interaural level difference (ILD) cues. Udesen et al[14] measured ILD at various locations around the pinna and showed up to a 30 dB error depending on location. Along with the fact that pinna compensation is not individualized, perhaps this is a contributing factor to the conclusion of a meta-analysis study that pinna compensation may be less helpful in the real-world than in laboratory settings.[22]

A HEARING AID SOLUTION THAT PRESERVES SPATIAL HEARING CUES

The ReSound Organic Hearing philosophy is shown by a legacy of looking to nature to inspire innovations in hearing aids, beginning with WDRC to mimic the frequency dependent compressive nonlinearity of the cochlea. ReSound also commercialized the open fit, uniting natural hearing of direct acoustic sound with high fidelity amplified sound in a comfortable and virtually invisible package. In fact, this remarkable innovation led the way to the popular RIE styles of today. With ReSound ONE, we again leverage nature by taking advantage of the individual wearer's ears to personalize the sound in a way no other technology can. The new M&RIE solution combines all the advantages of the RIE style with a microphone in the ear canal to deliver sound to each user's ear using their own unique ear anatomy. A microphone packaged in the tiny receiver module allows the sound to be picked up within the entrance to the user's ear canal, processed in the Over-The-Ear device and delivered by the receiver inside the ear canal. Microphones on the Over-The-Ear device mean that M&RIE can be combined with directional technology when additional boost in signal-to-noise ratio (SNR) is desirable. M&RIE allows users full benefit of binaural processing by the brain. When the spatially encoded information is presented to the brain in the format it expects, the benefits include better SNR, better estimation of direction of arrival of sound, better depth and distance perception, and synergy between the visual and auditory systems. All of this contributes to the most natural listening experience.

EVIDENCE SUPPORTING M&RIE

Technical measurements of M&RIE show that the filtering properties with its in-ear location are almost identical to the open ear. Figure 1 illustrates how M&RIE is situated on the ear with the yellow dots representing the microphone locations. In addition to the two microphones in the device above the ear, this solution has a microphone on the outside-facing part of the receiver module inside the ear canal. The three-dimensional plots show the intensity of different frequency sounds presented at angles from 0 to 360 degrees for an open ear, M&RIE and the pinna compensation algorithm using the microphones on top of the ear. While the pinna compensation algorithm roughly approximates the results with the open ear, the M&RIE preserves them very precisely.

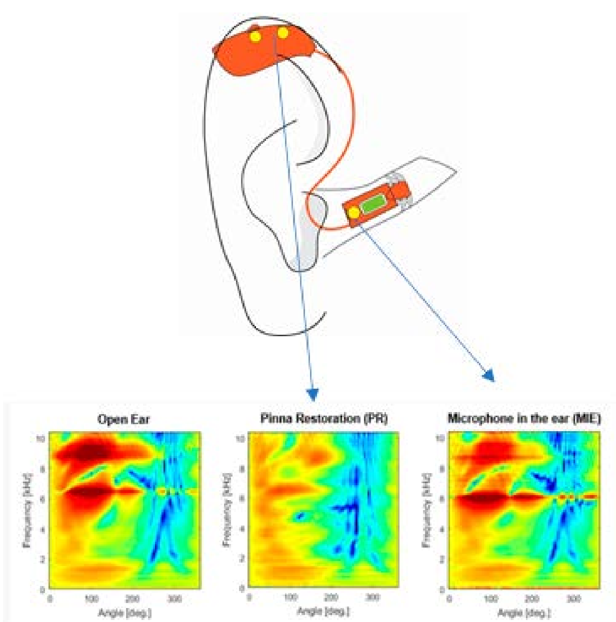

Figure 1. The M&RIE receiver module contains both a microphone and a receiver. The 3-dimensional plots show the intensity measured in the ear canal per frequency and angle of presentation for the open ear, a pinna compensation algorithm, and the M&RIE. Blue colors indicate less intensity, and red colors indicate greater intensity. With the M&RIE microphone location, the spectral filtering of the head and outer ear are nearly identical to that of the open ear canal. The pinna compensation algorithm using the two microphones above the ear is a good approximation, but is based on average data.

It is of course of even greater interest whether the M&RIE microphone location brings perceptual benefits that match the acoustic measurements. One way to get an impression of how spatial hearing may be affected is via a localization task. As mentioned, improvements in front-back localization have been reported for pinna compensation algorithms relative to omnidirectional microphones. To validate the benefit of localization with M&RIE compared to omnidirectionality and pinna compensation, an internal test was conducted including five adults with hearing thresholds within normal limits and 10 adults with audiograms similar to the standard N1, N2 and N3 audiograms.[23]

The listeners were seated in an array of 12 loudspeakers spaced 30 degrees apart and adjusted such that the participants' ears were on the same horizontal plane as the center of the speakers. Participants were encouraged to keep their heads stationary throughout the experiment. Signals were presented randomly from the speakers and each angle was tested 4 times, with a total of 48 signal presentations. The task was to identify the speaker where the signal originated, by naming the speaker number. Participants had a sketch of the speaker set-up on a piece of paper to help them. This test was repeated twice.

Results with five listeners with normal hearing thresholds represent the potential of the M&RIE solution. As can be seen in Figure 2, these listeners showed dramatic benefit of the pinna compensation both in front-back and overall localization. These listeners made 29% fewer front-back confusions on average with M&RIE than with omnidirectional. They made 17% fewer overall localization errors with M&RIE than with omnidirectional. They furthermore

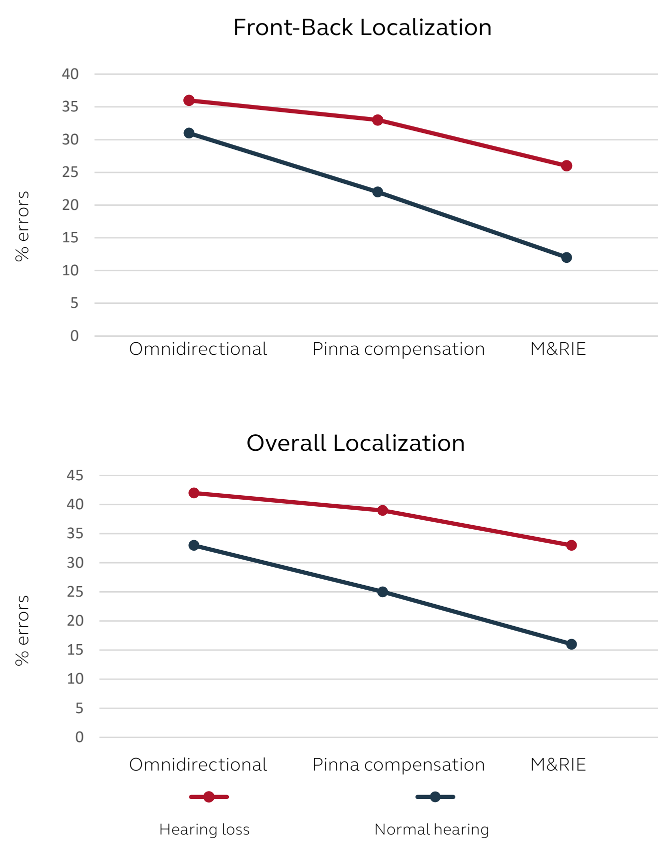

Figure 2. The top panel shows the percentage of errors on a front-back localization task while the lower panel shows percentage of errors for overall localization. Errors in localization decreased for both listeners with normal hearing and listeners with mild hearing loss with pinna compensation compared to omnidirectionality. Further benefit was shown with M&RIE.

showed equally as much benefit for M&RIE relative to pinna compensation, illustrating the importance of one's unique ear characteristics in localization. As expected, the ten listeners with hearing loss performed worse than those with normal hearing on all the localization tasks re gardless of the condition. It is well-established that people with hearing loss show degraded performance in this area, and that they are less sensitive to acoustic effects due to microphone location.[24,25] Although less dramatic than for the listeners with normal hearing, the listeners with mild hearing loss in the internal study did show benefit on average with both pinna compensation and M&RIE, although only results with M&RIE were significantly better. On average, front-back localization errors decreased by 10%, and overall localization errors by 9% relative to the omnidirectional condition. Notably, there was quite a lot of individual variation. This suggests that some individuals can better take advantage of the preserved localization cues than others despite similar hearing sensitivity.

Good spatial hearing is a contributor to our sense of naturalness of sound. It is part of what helps us perceive sounds as occurring outside the head, in space. It is therefore of interest also to ask listeners about their sound quality preferences as a function of microphone location. As an extension of the internal listening test, participants were given the opportunity to evaluate the three microphone conditions on a walk outdoors and in a crowded lunchroom. The hearing aids were programmed with omnidirectionality, pinna compensation and M&RIE in random order and both the participant and investigator were blinded to the conditions. Participants were asked to indicate a preference in terms of naturalness of the sound. Of the listeners with normal hearing, three of five preferred M&RIE, one preferred pinna compensation, and one preferred omnidirectional. Of the listeners with hearing loss, nine preferred M&RIE and only one preferred omnidirectional.

A more structured way to evaluate sound quality in hearing aids has been developed by Legarth et al[26] based on a MUSHRA approach.[27,28] Advantages of this method are that it is double-blinded, reliable and can overcome limitations of auditory memory. It has frequently been used to quantify both overall sound quality preferences as well as dimensions of sound quality in hearing aids. Participants listen to sound stimuli over headphones and rate them relative to high and low anchors. This method was also used to evaluate sound quality for the M&RIE concept relative to pinna compensation.

In order to evaluate sound quality resultant from microphone location, it is necessary for individuals to be able to evaluate the sound as it would be shaped by their unique anatomy as it arrives at the microphone. To make this possible for headphone listening, the sound stimuli for each listening condition needed to be modified according to a set of data derived from measurements of how sound presented from varying distances and directions was filtered by their anatomical features. Therefore, a set of filters for five listeners' right and left ears was determined for M&RIE microphone placement and for RIE microphone placement above the pinna, and then placed in the signal path between the sound stimuli and the headphones along with a correction for the headphone response. The result is a true reproduction of the naturally occurring sound pressures in their ears for each condition.

For the listening test, the five normal-hearing participants evaluated overall sound quality and spatial sound quality. For overall sound quality, they were to listen for clarity, timbre and naturalness. For spatial sound quality, they were to listen for ability to localize sounds, definition of sound, and spaciousness or sense of the room. The stimuli were created with a simulation tool[29] and included an office scene, a cafeteria scene and jazz music.

Results showed that the average overall quality rating and the average overall spatial quality rating for M&RIE was twice as high as for pinna compensation. What is most striking is the lack of variability in the M&RIE rankings versus the pinna compensation. For both the overall and spatial sound quality, the ratings of pinna compensation for individuals range from poor to nearly as good as M&RIE. This is an expected finding because the pinna

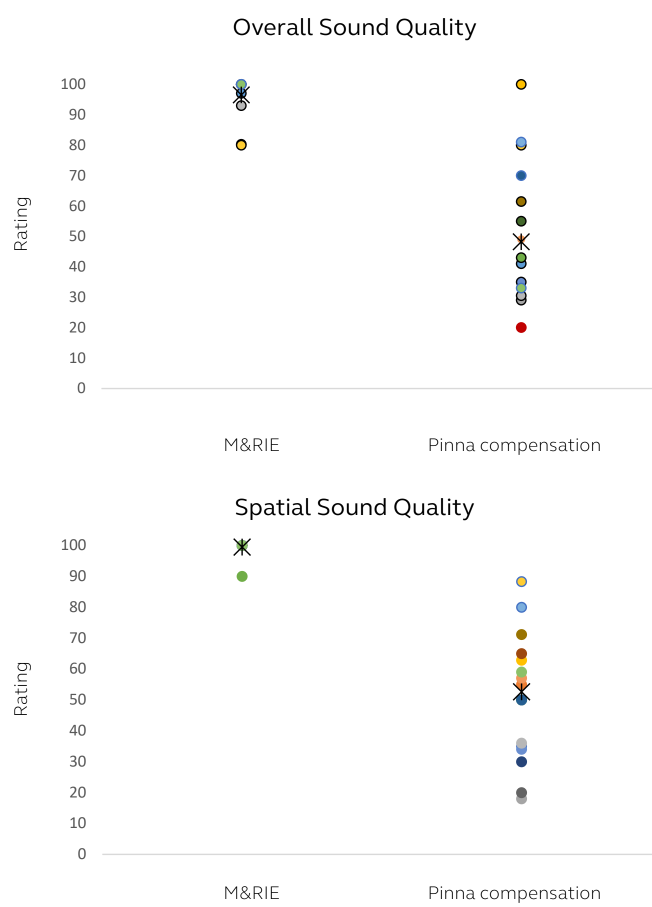

Figure 3. Individual ratings of overall sound quality and spatial sound quality for the M&RIE and pinna compensation. "X" shows the mean rating for each condition. Consistent high ratings with a small distribution were observed for the M&RIE. More variation in the results with pinna compensation reflect the variation of individual differences in how sound is filtered by the listener's individual anatomy.

compensation is based on an average adult. For people who have very different anatomical characteristics than this average, the sound delivered via pinna compensation will be less natural and of inferior quality to that picked up at the M&RIE microphone location. For those who have similar characteristics to the average, the sound via pinna compensation will be of quite good quality.

CAN LISTENING COMFORT BE AFFECTED BY MICROPHONE LOCATION?

A practical issue for hearing aid users is wind noise. Wind noise is an annoyance that occurs when hearing aids are exposed to wind and other air flows as users go about their daily activities. Such air flows can be generated by something as everyday as walking. Users are regularly exposed to greater wind noise annoyance as they engage in outdoor activities. Wind noise is caused by turbulent flow of air at the microphone ports, that is picked up by the microphones and amplified. It is worst for microphone locations that are close to obstructions that cause the turbulent airflow – like the pinna. Therefore, microphone location on top of or behind the pinna have the worst microphone placement in terms of wind noise. Even for the smaller RIE style that is better concealed by the pinna, this microphone placement is disadvantageous.[30] Hearing aid manufacturers have developed signal processing algorithms that can identify wind noise and reduce gain, but in terms of sound quality and maintaining audibility, this is vastly inferior to not having wind noise enter the hearing aid in the first place. Hearing aid microphone placement within the ear canal has been shown to dramatically reduce wind noise depending on orientation to the air flow.[31]

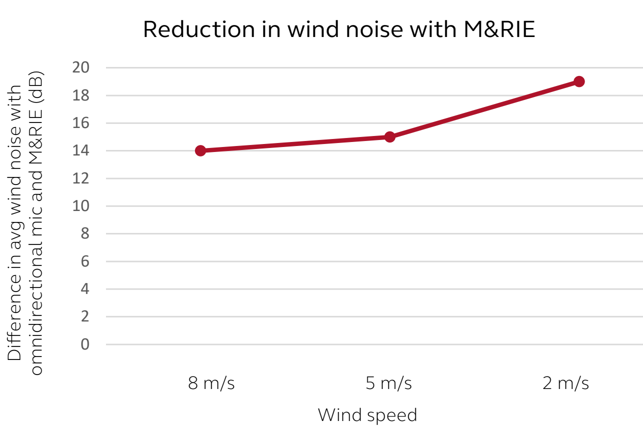

Figure 4. Reduction in wind noise with M&RIE compared to omnidirectional microphone on the RIE at different wind speeds.

Wind tunnel measurements comparing M&RIE to On-The-Ear microphone location are in agreement with other studies and confirm how the advantages of M&RIE extend to reduction of wind noise. A M&RIE receiver was attached to an RIE hearing aid and mounted on a KEMAR. Measurements of the output of all three microphones (the two microphones on the hearing aid located above the ear and the M&RIE in the ear canal) were taken at varying angles of incidence of wind at speeds of 2 m/s, 4 m/s and 8 m/s. Figure 4 shows the average reduction in wind noise across all angles for the M&RIE microphone location versus the front microphone location. The results compared to the rear microphone location on the hearing aid were similar. Wind noise was reduced by 14 to 19 dB with the M&RIE. At 5 m/s, which corresponds to a fresh breeze that could make small trees sway, the reduction in wind noise level with M&RIE compared to omnidirectional was 15 dB.

HOW DOES M&RIE FIT IN TO RESOUND ONE?

The candidate for the M&RIE solution will have a mild-to-moderate hearing loss. This group of users is likely to benefit most from access to the preserved high frequency spatial hearing cues. Vital spectral information for resolving front-back confusions as well as localization of sounds vertically is encoded in frequencies above 5000 Hz.[32] The ReSound ONE fit with the M&RIE shines with its extended high frequency bandwidth and ability to make these important cues available to the many users with milder hearing losses. Because the auditory system can adapt to some extent in localizing sound sources as a function of different hearing aid microphone location,[33,34] fitting new users with the M&RIE is likely to give them the most natural-sounding introduction to amplification because it will immediately bring them closer to “hearing with their own ears”.

All listeners, regardless of hearing status, intuitively apply different listening strategies based on the interaction of their listening intent and the acoustic environment. In some situations, natural sound quality and reliance on spatial hearing cues to segregate sounds in the environment are most important. In others where there is more interfering noise, enhancement of SNR gains importance in fulfilling listening goals. All Access Directionality is the evidence-based binaural hearing strategy that ReSound applies to support and leverage binaural hearing processes in the brain.[35] Within this strategy, people who are fit with the M&RIE will have the microphone in the ear canal active when they are in quiet, speech only, and relatively uncomplicated listening environments with limited interfering noise. In other environments, the strategy switches to use the microphones on the ReSound ONE devices to enhance SNR while maintaining access to surrounding sounds. M&RIE can also be activated in dedicated listening programs. For example, due to the significant protection against wind noise and the superior natural sound quality, M&RIE is selected as default in the Outdoor program.

SUMMARY

Many current and potential hearing aid users have mild-to-moderate hearing loss, and may be especially sensitive to degrading effects on localization and sound quality of the microphone location on the RIE style hearing aids which they are most likely to be fit with. Driven by the ReSound Organic Hearing philosophy, a new fitting option for RIE is introduced with ReSound ONE to solve this issue. Intended for those with milder hearing loss, the M&RIE encases both a receiver and microphone in the module which inserts into the user's ear canal. By picking up the sound in the ear canal, the unique sound filtering properties of the user's own anatomy are preserved, allowing the brain to receive the sound as nature intended. Benefits of M&RIE include better localization and spatial hearing and sound quality, even compared to pinna compensation algorithms. M&RIE is merged into All Access Directionality, the newest version of the ReSound binaural strategy for optimizing microphone settings according to the listening environment. M&RIE can also be selected for use in customized listening programs in ReSound ONE.

REFERENCES

1. Goman AM, Lin FR. Prevalence of hearing loss by severity in the United States. American Journal of Public Health. 2016 Oct;106(10):1820-2.

2. Strom K. Hearing aid unit sales increase by 6.5% in 2019. Hearing Review. 2020;27(2):6,34.

3. Carr, K. (2020). 20Q: Consumer insights on hearing aids, PSAPs, OTC devices, and more from MarkeTrak 10. AudiologyOnline. Retrieved from www.audiologyonline.com.

4. Griffing T, Preves D. In-The-Ear aids: Part 1. Hearing Instruments. 1976; 3:23-24.

5. Griffing T, Preves D. In-TheEear aids: Part 2. Hearing Instruments. 1976; 5:12-14,56.

6. Risberg DM, Cox RM. Comparison of In-The-Ear and Over-The-Ear hearing aid fittings. Journal of Speech and Hearing Disorders. 1986 Nov;51(4):362-9.

7. Festen JM, Plomp R. Speech-reception threshold in noise with one and two hearing aids. Journal of the Acoustical Society of America.1986; 79(2):465–471.

8. Pumford JM, Seewald RC, Scollie SD, Jenstad LM. Speech recognition with In-The-Ear and Behind-The-Ear dual-microphone hearing instruments. Journal of the American Academy of Audiology. 2000 Jan 1;11(1):23-35.

9. Westerman S, Topholm J. Comparing BTEs and ITEs for localizing speech. Hearing Instruments. 1985; 36(2): 20-24.

10. Cubick J, Buchholz JM, Best V, Lavandier M, Dau T. Listening through hearing aids affects spatial perception and speech intelligibility in normal-hearing listeners. The Journal of the Acoustical Society of America. 2018 Nov 20;144(5):2896-905.

11. Byrne D, Noble W. Optimizing sound localization with hearing aids. Trends in Amplification. 1998 Jun;3(2):51-73.

12. Gatehouse S, Noble W. The speech, spatial and qualities of hearing scale (SSQ). International Journal of Audiology. 2004 Jan 1;43(2):85-99.

13. Picou EM. MarkeTrak 10 (MT10) Survey Results Demonstrate High Satisfaction with and Benefits from Hearing Aids. Seminars in Hearing. 2020; 41(1):21-36.

14. Udesen J, Piechowiak T, Gran F, Dittberner AB. Degradation of spatial sound by the hearing aid. In Proceedings of the International Symposium on Auditory and Audiological Research 2013 Dec 15 (Vol. 4, pp. 271-278).

15. Van den Bogaert T, Carette E, Wouters J. Sound source localization using hearing aids with microphones placed Behind-The-Ear, In-The-Canal, and In-The-Pinna. International Journal of Audiology. 2011 Mar 1;50(3):164-76.

16. Denk F, Ewert SD, Kollmeier B. Spectral directional cues captured by hearing device microphones in individual human ears. The Journal of the Acoustical Society of America. 2018 Oct 11;144(4):2072-87.

17. Keidser G, Rohrseitz K, Dillon H, Hamacher V, Carter L, Rass U, Convery E. The effect of multi-channel wide dynamic range compression, noise reduction, and the directional microphone on horizontal localization performance in hearing aid wearers. International Journal of Audiology. 2006 Jan 1;45(10):563-79.

18. Gran F, Bønnelykke JR, Haastrup A, Udesen J, Fortune T, Piechowiak T, Dittberner A. Spatial cue reproduction in modern Receiver-In-Ear hearing instruments. In Proceedings of the International Symposium on Auditory and Audiological Research. 2011 Dec 15;3:441-448.

19. Keidser G, O'Brien A, Hain JU, McLelland M, Yeend I. The effect of frequency-dependent microphone directionality on horizontal localization performance in hearing-aid users. International Journal of Audiology. 2009 Jan 1;48(11):789-803.

20. Kuk F, Korhonen P, Lau C, Keenan D, Norgaard M. Evaluation of a pinna compensation algorithm for sound localization and speech perception in noise. American Journal of Audiology. 2013.

21. Groth, J. Hearing aid directionality with binaural processing. AudiologyOnline. 2016 May. Available from www.audiologyonline.com.

22. Xu J, Han W. Improvement of Adult BTE Hearing Aid Wearers' Front/Back Localization Performance Using Digital Pinna-Cue Preserving Technologies: An Evidence-Based Review. Korean Journal of Audiology. 2014; 18(3): 97.

23. Bisgaard N, Vlaming M, Dahlquist M. Standard audiograms for the IEC 60118-15 measurement procedure. Trends in Amplification. 2010; 14:113-120.

24. Akeroyd MA. An overview of the major phenomena of the localization of sound sources by normal-hearing, hearing-impaired, and aided listeners. Trends in Hearing. 2014 Dec 8;18:1-7.

25. Best V, Kalluri S, McLachlan S, Valentine S, Edwards B, Carlile S. A comparison of CIC and BTE hearing aids for three-dimensional localization of speech. International Journal of Audiology. 2010 Oct 1;49(10):723-32.

26. Legarth SV, Simonsen CS, Dyrlund O, Bramsloev L, Jespersen C. Establishing and qualifying a hearing impaired expert listening panel. Poster presentation at ICHON. 2012, Lake Tahoe.

27. Mason AJ. The MUSHRA audio subjective test method. BBC R&D White Paper WHP. 2002 Sep;38.

28. Liebetrau J, Nagel F, Zacharov N, Watanabe K, Colomes C, Crum P, Sporer T, Mason A. Revision of Rec. ITU-R BS. 1534. In Audio Engineering Society Convention 137 2014 Oct 8. Audio Engineering Society.

29. A.Wabnitz, N. Epain, C. Jin, and A. van Schaik. Room acoustics simulation for multichannel microphone arrays. In Proc. International Symposium on Room Acoustics, Melbourne, 2010.

30. Zakis JA, Hawkins DJ. Wind noise within and across Behind-The-Ear and miniature Behind-The-Ear hearing aids.
The Journal of the Acoustical Society of America. 2015 Oct 21;138(4):2291-300.

31. Zakis JA. Wind noise at microphones within and across hearing aids at wind speeds below and above microphone saturation. The Journal of the Acoustical Society of America. 2011 Jun;129(6):3897-907.

32. Langendijk EH, Bronkhorst AW. The contribution of spectral cues to human sound localization. The Journal of the Acoustical Society of America. 1999 Feb;105(2):1036.

33. Byrne D, Dirks D. Effects of acclimatization and deprivation on non-speech auditory abilities. Ear and Hearing. 1996 Jun;17(3 Suppl):29S-37S.

34. Whitmer WM, Schinkel-Bielefeld N, McShefferty D, Wilson C, Naylor G. Adaptation to hearing-aid microphone modes in a dynamic localisation task. InProceedings of the International Symposium on Auditory and Audiological Research 2019 (Vol. 7, pp. 197-204).

35. Groth J. The evolution of the ReSound binaural hearing strategy: All Access Directionality and Ultra Focus. ReSound white paper. 2020.

Manufacturer according to FDA:

GN ReSound North America

8001 E. Bloomington Freeway
Bloomington, MN 55420
USA
1.800.248.4327
pro.resound.com

ReSound Government Services

8001 E. Bloomington Freeway
Bloomington, MN 55420
USA
1.800.392.9932
gs.resound.com

Manufacturer according to Health Canada:

Resound Canada

2 East Beaver Creek Road, Building 3
Richmond Hill, ON L4B 2N3
Canada
1.888.737.6863
pro.resound.com

© 2020 GN Hearing A/S. All rights reserved. ReSound is a trademark of GN Hearing A/S.

MK605331

MK605331 Rev B 2020.08