WIDEXPRESS

WIDEX

FEBRUARY 2024 . ISSUE NO . 54

INTRODUCING THE WIDEX SMARTRIC™: WHEN DESIGN MEETS PERFORMANCE

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At Widex, we believe that the natural auditory system is best equipped for processing detailed and authentic sound. We therefore manipulate less to craft a more natural hearing experience and only use drastic processing when needed. Overall, our goal is to provide a sound so natural that people forget about their hearing loss.

To pursue our goal consistently, we follow our sound philosophy (Ziegler et al., 2023) and make design decisions accordingly. To this end, the Widex sound philosophy is grounded in three fundamental principles: Principle 1: Respect All Sounds; Principle 2: Tailor to the User; and Principle 3, which is especially relevant for this article: Focus on What Matters. With the third principle, Focus on What Matters, we strive to create a seamless sound experience that is optimized for real-life hearing, allowing the user to stay focused on the sound they want to hear, without losing awareness of their environment. In our latest innovation, we use a unique hearing aid design to achieve just that: helping the user focus on what matters.

We are proud to introduce our new Widex SmartRIC™, in a groundbreaking L-shaped form factor that combines great design with great sound. Importantly, the great design – shown in Figure 1 – is not only for the sake of offering users an attractive look and feel, but also because the design choices support important audiological benefits. This makes the SmartRIC an attractive solution for many different types of users: users with communication needs in background noise can benefit from improved directionality; active users can enjoy the reduced wind and touch noise; and people on the move will appreciate excellent battery life and a stylish portable charger. In addition to these new improvements, the SmartRIC comes, of course, with the signature Widex natural sound for natural hearing, supported by many specific features such as TruAcoustics, which tailors the sound to the individual user, and the PureSound program for users with mild-to-moderate hearing loss. This article describes a range of studies and measurements that show the multiple benefits of the SmartRIC for its broad group of potential users. These include improved directionality (Study 1), reduced wind noise (Study 2), reduced touch noise (Study 3), and great usability (Study 4), as well as improved battery life and charger portability.

Figure 1: Illustration of the Widex SmartRIC and its portable charger.

STUDY 1: IMPROVED DIRECTIONALITY

A central concern for hearing-aid users is understanding speech in noise, with directional microphone technology arguably being the most efficient signal-processing strategy to provide the user with a better signal-to-noise ratio (Kumar et al., 2023). However, directionality is not a mechanism that should be uncritically set up to be as aggressive as possible. In fact, more aggressive processing comes at the cost of a more unrecognizable background noise, a more unnatural sound, and an overall auditory scene that is more difficult to decode. This all goes against the Widex sound philosophy (see Ziegler et al., 2023), with its focus on providing a natural and authentic sound, while also supporting the user with appropriate directionality for a balance between focus and awareness.

Reducing the microphone angle

The directionality improvements in the SmartRIC are the result of the angle between the horizontal plane and the (imaginary) line between the two microphone inlets on the hearing aid being smaller than on previous Widex receiver-in-canal (RIC) devices, as well as on other devices on the market (Fels, 2017). We call this the 'microphone angle' in this paper; the term 'tilt angle' is also sometimes used. The difference between the microphone angle of a regular RIC hearing aid and the smaller microphone angle of the SmartRIC is illustrated in Figure 2. The smaller the angle, the better the directional algorithms can isolate the appropriate target signal in front of the user, e.g., a speaker the hearing aid user wants to focus on. When the angle increases, the directional beam points less forward from the user and more upward, where the target signal is less likely to originate.

The reason why small microphone angles are better for directivity for signals in front of the wearer is that the directional algorithms are based on the horizontal distance between the two microphone inlets, utilizing the fact that the sound from a given sound source arrives at the two microphones at (slightly) different times. When the microphone angle is 0 degrees (i.e. with the two microphones placed in the same horizontal plane), the horizontal distance between the microphones is maximized, but as the angle increases, the horizonal distance becomes smaller, making the directional algorithms less efficient for sounds from the front. Some degree of tilt can be accepted, but a certain minimum distance is necessary, and it is important that the actual angle does not deviate too much from the angle assumed in the hearing aid design, making this an important parameter to measure and control.

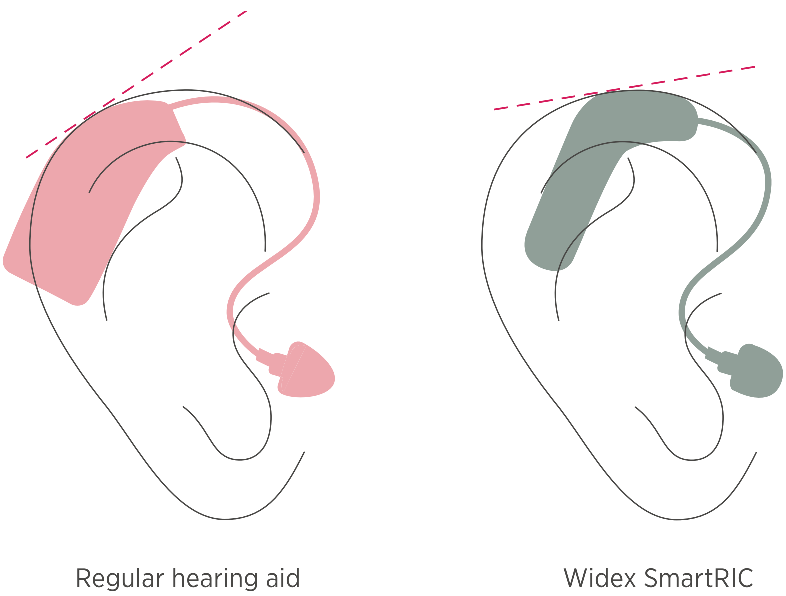

Figure 2: Stylized drawing of the microphone angle on the SmartRIC (right) compared with the larger angle often found on other RICs (left).

In a study, the microphone angle of the SmartRIC was measured on 20 people, with 10 females and 10 males and a mixture of participants from Europe and Asia with different ear anatomies. In these measurements, the SmartRIC was placed on the ear of the participant as it would be during normal use. The participant was asked to look straight ahead, and a photo was taken from the side. An external marker (parallel with the line connecting the microphone inlets) was placed on the hearing aid to ease the determination of the angle based on the photo. The distribution of the measured microphone angles is shown in Figure 3.

The SmartRIC had a mean microphone angle of 17 degrees, which represents an improvement over previous Widex RIC devices. Moreover, this mean value is below the lowest individual microphone angle for RIC devices reported for 40 users by Fels (2017), and it is more than 20 degrees below the mean microphone angle in the data shown by Fels (where the mean angle can be deduced from their Figure 1 to be 41 degrees). That article does not specify which RICs the measurements were done with, but the comparison between the angles reported by Fels and those observed for the SmartRIC clearly shows the superiority of the SmartRIC in terms of microphone angle, which is a main prerequisite for efficient directional processing.

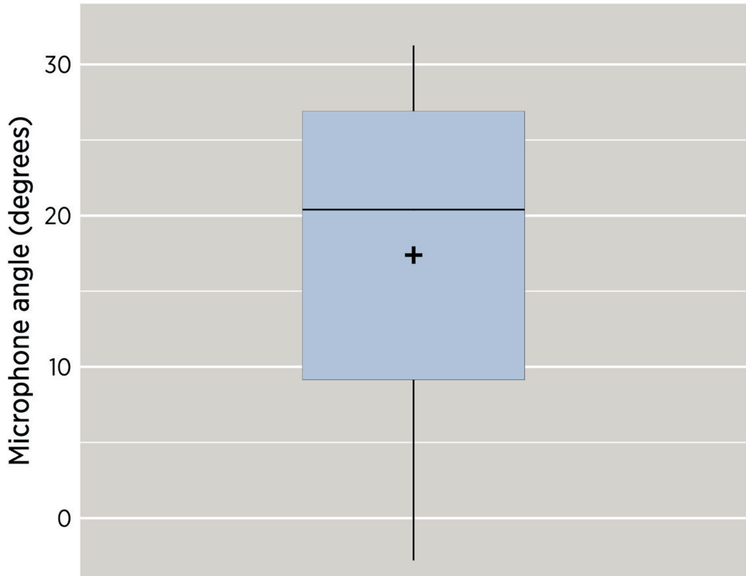

Figure 3: Distribution of microphone-angle measurements on 20 people wearing the Widex SmartRIC. The box represents the middle 50% of the data, from the first to the third quartile, with the line in between representing the median. The cross shows the mean, and the whiskers show the minimum and maximum values observed.

Microphone angle and directivity index

To understand the relationship between microphone angle and directionality in more detail, it is worth considering the relationship between the microphone angle and the hearing aid's directivity index (DI; American National Standards Institute, 2021). The directivity index is a measure of how well the hearing aid suppresses sounds coming from non-target directions, i.e., comparing sound directly from the front to sound coming from all other angles. The DI is typically measured with the hearing aid fitted on a Knowles Electronics Manikin for Acoustic Research (KEMAR). For directional microphone systems with a hypercardioid polar pattern like the one created by the two microphones and the directional algorithms used in the SmartRIC, the theoretical maximum DI is 6 dB, but this is for the microphone placed in free field. When placed on a KEMAR, the DI will typically be substantially lower, due to the interaction with the pinna and the head (Dittberner & Bentler, 2003).

The DI is interesting because it gives an indication of the SNR improvement that a hearing aid with a directional microphone system can provide relative to an ideal omnidirectional microphone, when the user listens to a talker in the front while noise is coming from all directions. The SNR improvement will directly support better speech intelligibility in noise. However, as mentioned above, there are also drawbacks of aggressive directionality, so a high DI does not necessarily lead to a good user experience.

The relationship between microphone angle and DI is illustrated in Figure 4. The figure shows the DI plotted as a function of the microphone angle for a series of measurements performed on an experimental test hearing aid that allows the microphone angle to be varied when placed on the ear of the KEMAR. The figure shows that the DI is highest for the lower microphone angles and reduced when the microphone angle increases. Furthermore, the figure shows that changing the microphone angle by, for example, 20 degrees – as observed in the comparison of the measured SmartRIC mean microphone angle and the data reported by Fels (2017) – can have a substantial effect on the DI. The absolute value of the DI varies between different directional algorithms and philosophies, but the impact of the microphone angle will be relevant regardless of the mechanism, and a reduced DI means that noise sources are less attenuated relative to the signal.

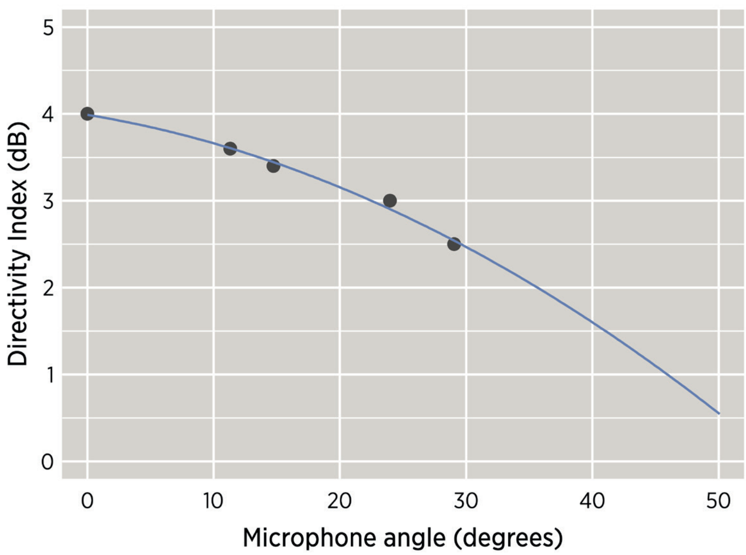

Figure 4: The relationship between microphone angle and directivity index. The dots represent measurements of microphone angle and DI, while the curve is a second order polynomial fit to the observed data.

SmartRIC improves directionality

To assess the directional advantage of the SmartRIC, the DI was measured by the FORCE Technology institute according to the ANSI/ASA S3.35-2021 standard (American National Standards Institute, 2021). The Widex Moment mRIC hearing aids were used as a reference, which allowed an investigation of the effect of the smaller microphone angle offered by SmartRIC when compared to the more regular microphone inlet positions used in the Moment mRIC hearing aids. The measurements were done at 1/3 octave frequencies from 500 to 5 kHz, with the hearing aids placed on the left ear of KEMAR. Figure 5 shows the measured difference in DI between the SmartRIC and the Moment mRIC. The difference is positive, indicating a higher DI provided by the SmartRIC, across the entire frequency range, and it increases at the two highest frequencies (4 and 5 kHz). The average DI difference (calculated according to the ANSI/ASA standard) was 0.8 dB. This result clearly shows the directional benefit offered by the smaller microphone angle allowed by the SmartRIC design.

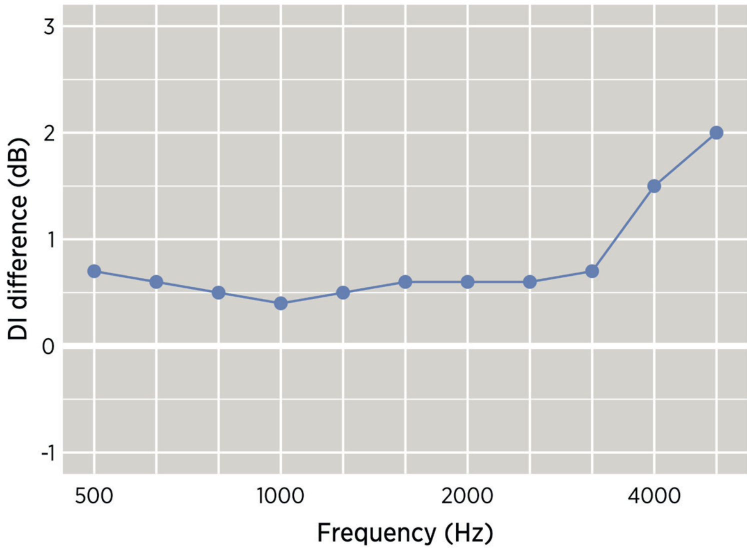

Figure 5: Difference in directivity index between the SmartRIC and the Moment mRIC, plotted as a function of frequency for the 1/3 octave frequencies from 500 Hz to 5 kHz. Positive values indicate a higher DI for the SmartRIC.

The 0.8-dB difference in average DI value may be translated into a speech intelligibility improvement by considering the slope of the psychometric function (or the performance-intensity function) that traditionally has been used to illustrate the relationship between the signal-to-noise ratio (SNR, in dB) and speech intelligibility (in percent). Using the slope of 12.3 %/dB, which was reported by MacPherson & Akeroyd (2014) as the median slope observed in studies investigating speech intelligibility of real sentences in static background noise, the 0.8-dB DI improvement corresponds to an improvement in speech intelligibility of around 10%, which can make a substantial perceptual difference to the user.

In practice, the psychometric function depends on the type of speech and noise and on individual characteristics like age and hearing loss. Thus, the slope depends on both the situation and the listener and is therefore highly variable. This means that the speech intelligibility benefit perceived by the individual user may be both smaller and larger than 10% in a given situation. Furthermore, it should be acknowledged that DI is an indication of the performance in a diffuse sound field (with noise coming from all directions). In a scenario with noise coming from a specific direction, two hearings aids with similar DI – but different directional microphone characteristics (as measured polar patterns) – may give rise to very different levels of benefit.

The relationship between microphone angle and directionality is important not only for the SmartRIC but also more broadly relevant for clinicians to be aware of, because it means that the placement of a hearing aid on the ear is an important determinant of the efficacy of the directional performance (see also Fels, 2017). This role of the placement means that clinicians should consider the microphone angle when choosing receiver length. Depending on the form factor, there may be some trade-off between how visible the hearing aid is on the ear and how well the microphones are placed, with the more invisible placement behind the ear resulting in a larger and therefore less ideal microphone angle. The hearing care professional should consider each client's needs and may sometimes need to balance visibility and function. This is less of an issue for the SmartRIC, which is designed to keep the angle low, but would be a relevant consideration for many RICs across brands.

Importantly, the directionality advantage for the SmartRIC is not about a more aggressive directional processing, with the associated problems outlined above, but about the hardware giving the directional algorithms the best possible operating conditions. As we saw above, microphone angle alone may provide a substantial directivity index advantage compared to other RICs, without making the directional algorithm more aggressive.

STUDY 2: REDUCED WIND NOISE

The reduced microphone angle with the associated directionality improvement is not the only audiological benefit of the SmartRIC design: the design of the microphone inlets themselves also results in improvements. More specifically, the mechanical design of the SmartRIC places the microphone inlets at the side of the hearing aid and has the microphone cover level with the rest of the device. This improves the aerodynamic flow and means that the inlets do not face oncoming wind, which reduces the noise created by wind and turbulence when the user is moving outdoors. Although wind noise can also be reduced during signal processing, a cleaner input signal due to the improved mechanical design is a major improvement.

In order to optimize the design, wind noise measurements were conducted at several stages during development. These measurements were conducted with the hearing aids on a KEMAR in a wind tunnel (see Figure 6). This allows precise measurement of the noise at different specific wind speeds and from different directions.

Study 2 consists of wind noise measurements on the final SmartRIC form factor, compared to the Widex Moment mRIC. The measurements were conducted with the hearing aids in a so-called test mode, where the microphones are in omnidirectional mode and the signal processing reduced as much as possible to isolate the effect of the mechanical design. The test gain was set to a flat gain, and all adaptive algorithms that could affect the noise measurements were disabled. The hearing aids were mounted on the left ear of the KEMAR, and their positions on the ear were carefully matched.

The study included two wind speed conditions – 3 m/s (a light breeze) and 6 m/s (a moderate breeze) – and two angles of wind incidence – directly from the front (0º) and from the back (180º). Ten-second measurements were repeated three times for each hearing aid type (comparing the SmartRIC to the Widex Moment mRIC). The results were averaged across the three repetitions.

Figure 6: Measurement setup for wind noise, with the KEMAR positioned for wind from 0 degrees.

The results of the wind noise measurements for the two wind speeds are displayed in Figure 7, with frequency (in Hz) on the horizontal axis and input-referred noise (in dB re. 20 μPa/√Hz) on the vertical axis. For both wind directions (front direction in the left panel and back direction in the right panel) and for both wind speeds, the graphs show an advantage for the SmartRIC, with all SmartRIC (blue) curves falling below the corresponding Moment mRIC (red) curves at all frequencies, and with differences of up 20 dB being observed for wind coming from the back (right panel). With A-weighting applied to account for the frequency-dependent loudness perception, the average benefit is a 4-dB reduction in input-referred noise with wind coming from the front (at both wind speeds) and reductions of 17 dB and 15 dB with wind from the back (at 3 m/s and 6 m/s, respectively). Importantly, as the graph shows, and especially for wind from the back, the benefit is largest in the lower end of the frequency scale, where the wind noise is also the loudest.

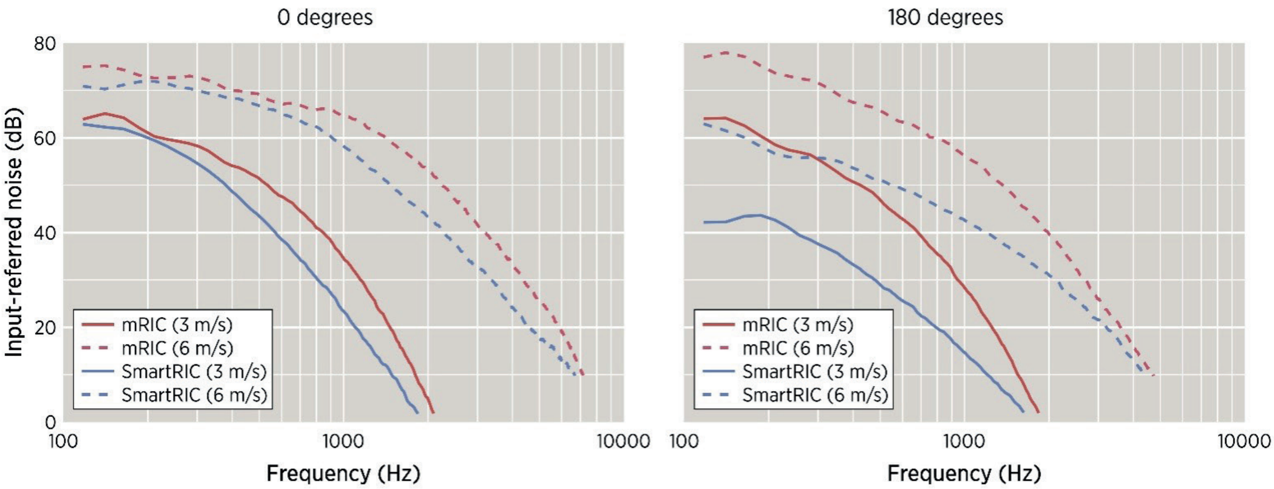

Figure 7: Wind noise measurements for the SmartRIC (blue curves) and Moment mRIC (red curves) for wind coming from the front (left) and the back (right), at wind speeds of 3 m/s (solid curves) and 6 m/s (dashed curves). The curves are shown up to frequencies where the system noise floor starts to exceed the wind noise.

These measurements on KEMAR have the advantage of being controlled, precise and possible to replicate. At the same time, we would expect considerable variation in the wind noise experience for the user, depending on how the device sits on their ear and on the wind speed (which is of course variable outside the lab) and its direction (which may be from different directions at the same time in natural conditions). It should also be noted that the measurements were done with the Widex wind noise attenuation (Korhonen, 2021) deactivated. When out in the real world, users will experience further reduction of wind noise due to this type of signal processing. However, reducing the noise at its source, as it is done in the design of the SmartRIC microphone inlets, is always a major benefit.

STUDY 3: REDUCED TOUCH NOISE

The redesigned microphone inlets that give the wind noise benefits shown above also have a positive effect on touch noise, i.e., the noise that the user may notice when they touch their hearing aids. This improvement was assessed in a study with 10 normal-hearing listeners who rated the perceived loudness of the touch noise, again comparing the SmartRIC against the Widex Moment mRIC.

Similar to the wind noise measurements, the hearing aids were in a test mode, providing a flat gain. The acoustic response of the SmartRIC hearing aid was equalized to match the response of the Moment mRIC, which enabled listeners to rate the hardware difference without distraction from any differences in acoustic response.

Each of the two hearing aids being compared was held in a fixed position and connected to an acoustic coupler. The output sound was routed via a sound card (where the equalization was applied) to a set of headphones, enabling the listeners to directly compare the output sounds from the two hearing aids.

The 10 listeners who took part in Study 3 were six males and four females aged between 30 and 57 years, with a mean age of 43 years. They were all untrained listeners with self-reported normal hearing.

The task for the listeners was to touch the hearing aid shells on and around the microphone cover (see Figure 8), using both tapping (up-down) and swiping (front-back) motions, and then to fill in questionnaires rating the resulting touch noise for each hearing aid on a scale from 0 (no noise) to 10 (very loud noise).

Figure 8: The SmartRIC subjected to a finger touch in the touch noise test. The SmartRIC was connected to an acoustic coupler and routed to headphones.

The results showed mean ratings of 2.6 for the SmartRIC and 6.6 for the Moment mRIC. Thus, the loudness of the touch noise was rated 4 scale points lower for the SmartRIC, which is highly significant according to a paired t-test ($t = 7.44$, $p = .00004$) and has a very substantial effect on a 10-point scale.

In order to understand the degree of improvement, we divided the difference between the two ratings by the baseline rating (i.e., the mRIC rating) to express the improvement in percent. As shown in Figure 9, which shows the individual improvements, all participants rated the touch noise more favorably for the SmartRIC, with improvements in a range from 33% to 88% and an average improvement of 59%.

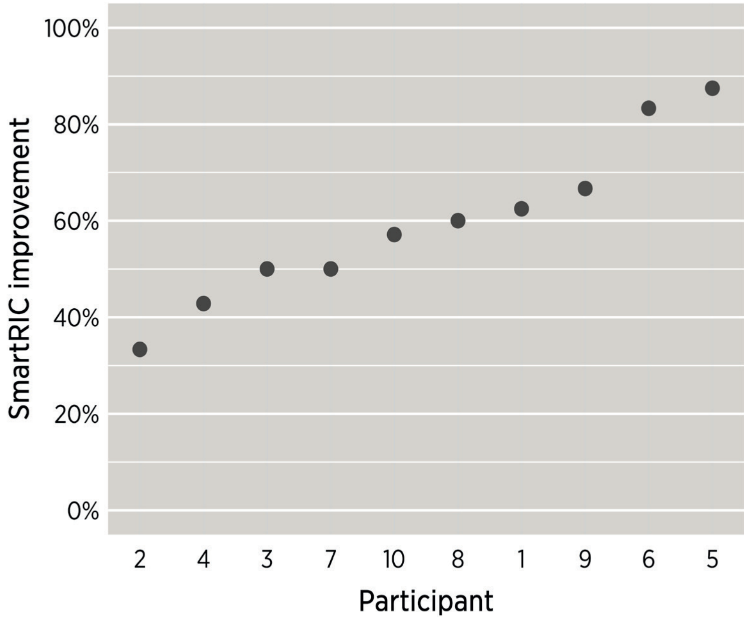

Figure 9: The rank-ordered relative improvement in rated touch noise for the SmartRIC(on the vertical axis) for each participant (on the horizontal axis), calculated as the difference between the two ratings divided by the baseline rating for the Moment mRIC.

In sum, Study 2 and 3 both show the benefits of the redesigned microphone inlets, with reductions in both wind and touch noise. The wind noise reduction is likely to be particularly beneficial for active users who spend time outdoors. The touch noise improvements are more of a detail, in the sense that users are unlikely to touch their SmartRIC frequently. However, even design details like these contribute – along with numerous other Widex features – to helping users forget about their hearing loss.

STUDY 4: DESIGN AND USABILITY

The impression of the design and the experience of handling and wearing the SmartRIC in real life were assessed in a usability study involving 12 participants (10 males, 2 females). They were all experienced hearing aid users, and their age was between 64 and 81 years (average 75 years). The participants were fitted with the SmartRIC, which they were asked to wear in their own daily environment for a period of one week. At the end of the trial period, they were asked to rate their experience using and handling the SmartRIC, both regarding the user-friendliness of the hearing aids and the accompanying portable charger.

The questions asked addressed the following aspects: the visual design; how easy it was to place the hearing aids on the ears; the wearing comfort; and – for the charger – the overall user-friendliness and how easy it was to place and remove the hearing aids. All questions were rated on a 10-point scale from 0 to 10, where low ratings indicated low levels of satisfaction and high ratings indicated high levels of satisfaction. The end points of the scales were labelled according to the specific question, e.g., "very difficult" (0) and "very easy" (10) in the question on how easy it was to place the hearing aids in the ear.

Figure 10 shows the mean ratings across participants for each of the questions. All mean ratings exceeded 8, indicating a high level of satisfaction with the design, wearing comfort and user-friendliness of the SmartRIC, as well as the user-friendliness of the charger.

Figure 10: Mean ratings across 12 participants on questions related to the design and usability of the SmartRIC and the portable charger. In all questions, a high rating indicates a high level of satisfaction.

On the question about how they liked the visual design, it was quite striking that 11 of the 12 ratings were in the range 7-10, whereas only one participant provided a rating (3) in the lower end of the scale, indicating some dissatisfaction with the visual design. Thus, even though the SmartRIC design was very different from what they were used to with their own hearing aids, the design was highly appreciated and easily accepted by the majority of participants. The high ratings of the design were accompanied by high ratings of both ease of placement on the ear and wearing comfort – showing the same pattern, with most ratings being in the upper end of the scale. The same was the case for the ratings of the charger usability. Together, these findings suggest a high level of satisfaction with the design and usability of the SmartRIC and the portable charger.

BATTERY LIFE

A further advantage of the design of the SmartRIC is not audiological but a major benefit in terms of usability and convenience, namely the way the device is powered. This has two aspects: the battery life of the hearing aids themselves and that of the portable charger, which functions as a power bank for the hearing aids.

The battery-life benefit of the SmartRIC is – like its other functional benefits – a result of the design, which integrates form and function in a unique way. With a battery capacity of 26 mAh, this is the longest-lasting battery in the Widex RIC portfolio and unrivalled by similar RIC devices from other manufacturers. The battery capacity translates into 37 hours of use without streaming or 27 hours of use with eight hours of streaming. This means that even the most persistent streamers will be able to use the hearing aids for more than a full day without charging.

Design is of course also a key attraction of the elegant, portable charger (see Figure 1 above), which has a capacity of 650 mAh and allows five full charges of the hearing aids. This means that the user can easily go more than a week without having to plug the charger in.

GREAT HARDWARE, GREAT SOLUTIONS

While this article has focused on the hardware design of the SmartRIC and its associated benefits, hearing aids are of course more than their hardware. The SmartRIC represents the best of Widex, not only in terms of hardware and craftmanship, but also in terms of the sound and signal processing, coming as it does with a range of important Widex features.

On the most general level, the SmartRIC provides the user with the signature natural sound set out by the Widex sound philosophy. This natural sound is driven by a whole range of signal processing, including the large input dynamic range (Boissonneault, 2015), the time-domain filter bank (Balling et al., 2022), and the predominantly slow compression (Boike & Souza, 2000; Hansen, 2002; Neuman et al., 1995; Souza et al., 2015; Windle et al., 2023). Importantly, this fundamental belief in natural sound also underlies the way the directionality is applied, with an emphasis on balancing focus and awareness. The SmartRIC supports this balance by offering an improved starting point for the directional algorithms.

An important user group for the SmartRIC is those with mild-to-moderate hearing loss, who are likely to be benefit from the Widex PureSound program. This program is designed with minimal signal processing delay in order to reduce the comb-filtering artefact that arises when direct and amplified sound mix at the eardrum of those with open and vented fittings, i.e., users with milder hearing losses. The PureSound program comes with a range of benefits, including preferred sound quality (Balling et al., 2020; Lelic et al., 2022), a more robust neural representation (Slugocki et al., 2020; Zhou et al., 2023), and a better spatial experience (Balling, Townend, et al., 2021; Korhonen et al., 2022). Users with milder hearing losses and open fittings are of course potential users of any RIC device, but the modern, stylish design of the SmartRIC may appeal especially to the younger users who are likely to dominate this group.

Another signature Widex feature is the My Sound functionality in the Moment app, which uses Artificial Intelligence (AI) to help users customize their sound whenever they feel like it. An app-based AI solution may also be assumed to appeal predominantly to a younger user group; however, a recent survey showed that users aged 75 years and above represent more than 30% of a sample of almost 4,000 app users (Ziegler et al., 2023). The My Sound functionality is unique in combining real-time AI with the individual user's situation and preferences to create a sound that is uniquely suited for that person in any given situation (Balling, Molgaard, et al., 2021).

In addition to offering this way of personalizing the sound in real life, tailoring of the sound is also a crucial part of the fitting of Widex hearing aids in the clinic, which also applies to the SmartRIC. This relies on two key features: TruAcoustics™, which accounts for individual venting and resonances (Balling et al., 2019; Cubick et al., 2022), and the Sensogram, which adjusts both gain and feature settings based on hearing thresholds measured with the hearing aid on the ear. This detailed fitting flow has been linked to an experience of fewer follow-up appointments being necessary with Widex than with other hearing aid brands (Helmink & Sasaki-Miraglia, 2023; Ziegler et al., 2023).

CONCLUSION

In sum, the SmartRIC offers something for many different types of users, whether they have a mild or more severe hearing loss, whether they are new or experienced users, or whether they are younger or older users. This means that the hearing care professional can offer the SmartRIC both as an attractive introduction to the unique Widex sound and craftmanship for new users, and as an appealing upgrade for existing Widex users.

REFERENCES

American National Standards Institute (2021). Method of measurement of performance characteristics of hearing aids under simulated real-ear working conditions. ANSI/ASA S3.35-2021.

Balling, L. W., Jensen, N. S., Caporali, S., Cubick, J., & Switalski, W. (2019). Challenges of Instant-Fit Ear Tips: What Happens at the Eardrum? *Hearing Review, 26*(12), 12–15.

Balling, L. W., Molgaard, L. L., Townend, O., & Nielsen, J. B. B. (2021). The Collaboration between Hearing Aid Users and Artificial Intelligence to Optimize Sound. *Seminars in Hearing, 42*(3), 282–294. https://doi.org/10.1055/s-0041-1735135

Balling, L. W., Mosgaard, L. D., & Helmink, D. (2022). Signal Processing and Sound Quality. *Hearing Review, 29*(2), 20–23.

Balling, L. W., Townend, O., & Helmink, D. (2021). Sound quality for all: The benefits of ultra-fast signal processing in hearing aids. *Hearing Review, 28*(9), 32–35.

Balling, L. W., Townend, O., Stiefenhofer, G., & Switalski, W. (2020). Reducing hearing aid delay for optimal sound quality: a new paradigm in processing. *Hearing Review, 27*(4), 20–26.

Bentler, R., Wu, Y. H., & Jeon, J. (2006). Effectiveness of directional technology in open-canal hearing instruments. *Hearing Journal, 59*(11), 40–47. https://doi.org/10.1097/01.HJ.0000286217.69092.39

Boike, K. T., & Souza, P. E. (2000). Effect of Compression Ratio on Speech Recognition and Speech-Quality Ratings With Wide Dynamic Range Compression Amplification. *Journal of Speech Language and Hearing Research, 43,* 456–468. https://doi.org/10.1044/jslhr.4302.456

Boissonneault, A. (2015). Narrowing the Gap: A Compilation of Dream Evidence. *WidexPress,* 35.

Cubick, J., Caporali, S., Lelic, D., Catic, J., Damsgaard, A. V., Rose, S., Ives, T., & Schmidt, E. (2022). *The Acoustics of Instant Ear Tips and Their Implications for Hearing-Aid Fitting.* https://doi.org/10.1097/AUD.0000000000001239

Dittberner, A., & Bentler, R. (2003). Interpreting the directivity index (DI). *Hearing Review, 10*(6), 16-21.

Fels, L. (2017). Directional microphones: Are we going in the right direction? In *Phonak Audiology Blog.* https://audiologyblog.phonakpro.com/directional-microphones-effects-of-microphone-orientation/

Hansen, M. (2002). Effects of Multi-Channel Compression Time Constants on Subjectively Perceived Sound Quality and Speech Intelligibility. *Killion, Reference Note, 23,* 369–380. https://doi.org/10.1097/01.AUD.0000028009.11739.3E

Helmink, D., & Sasaki-Miraglia, J. (2023). *Ask the Experts: How Fitting Widex Improves the Hearing Care Professional's Clinical Experience* (50).

Korhonen P. 2021. Wind Noise Management in Hearing Aids. *Seminars in Hearing,* 42(3), 248-259. https://doi.org/10.1055/s-0041-1735133

Korhonen, P., Kuk, F., Slugocki, C., & Ellis, G. (2022). Low processing delay preserves natural cues and improves spatial perception. *Hearing Review, 29*(6), 20–25.

Kumar, S., Guruvayurappan, A., Pitchaimuthu, A. N., & Nayak, S. (2023). Efficacy and Effectiveness of Wireless Binaural Beamforming Technology of Hearing Aids in Improving Speech Perception in Noise: A Systematic Review. *Ear and Hearing, 44*(6), 1289–1300. https://doi.org/10.1097/AUD.0000000000001374

Lelic, D., Stiefenhofer, G., Lundorff, E., & Neher, T. (2022). Hearing aid delay in open-fit devices: Preferred sound quality in listeners with normal and impaired hearing. *JASA Express Letters, 2*(10), 104803. https://doi.org/10.1121/10.0014950

MacPherson A. & Akeroyd M.A. 2014. Variations in the slope of the psychometric functions for speech intelligibility: a systematic survey. *Trends in Hearing, 18.* https://doi.org/10.1177/2331216514537722

Neuman, A. C., Bakke, M. H., Mackersie, C., Hellman, S., & Levitt, H. (1995). Effect of release time in compression hearing aids: Paired-comparison judgments of quality. *The Journal of the Acoustical Society of America, 98*(6), 3182–3187. https://doi.org/10.1121/1.413807

Slugocki, C., Kuk, F., Korhonen, P., & Ruperto, N. (2020). Neural Encoding of the Stimulus Envelope Facilitated by Widex ZeroDelay Technology. *Hearing Review, 27*(8), 28–31.

Souza, P. E., Arehart, K. H., Shen, J., Anderson, M., & Kates, J. M. (2015). Working memory and intelligibility of hearing-aid processed speech. *Frontiers in Psychology, 6*(MAY). https://doi.org/10.3389/fpsyg.2015.00526

Windle, R., Dillon, H., & Heinrich, A. (2023). A review of auditory processing and cognitive change during normal ageing, and the implications for setting hearing aids for older adults. In *Frontiers in Neurology* (Vol. 14). Frontiers Media SA. https://doi.org/10.3389/fneur.2023.1122420

Zhou, M., Soleimanpour, R., Mahajan, A., & Anderson, S. (2023). Hearing Aid Delay Effects on Neural Phase Locking. Ear & Hearing. https://doi.org/10.1097/aud.0000000000001408

Ziegler, J., Balling, L. W., Helmink, D., & Marcoux, A. (2023). The Widex Sound Philosophy: A Global Perspective on Natural Sound, Innovative Technology, and User Satisfaction. *WidexPress, 54.*