OPTIMIZING SOUND IN SIGNAL PROCESSING AND HEARING AID FITTING

By Laura Winther Balling, Ph.D. and Dana Helmink, Au.D.

The Widex MOMENT™ hearing aid platform brings two major innovations in sound. With the introduction of the TruAcoustics™ fitting formula, it provides an easier, more accurate way to adjust gain to the individual hearing loss and the acoustics of the individual ear canal for all users, but with a special focus on those using instant tips. The solid fitting of TruAcoustics provides the necessary foundations for the most revolutionary innovation in MOMENT: the radical reduction of signal processing delay implemented in the PureSound™ program for mild-to-moderate hearing losses.

These innovations are the latest in a long history of focusing on sound quality. This focus means that all design choices are made with the purpose of creating the most natural sound possible: a sound at the eardrum that is accurate, complete, and free from distortions. Design choices such as the decision to build a filter bank in the time domain and setting a sampling rate as high as 33.1kHz ensure that sound quality is not only maintained but exceeds what many considered necessary in hearing aids.

Choosing a time-domain filter bank initially makes it more challenging to optimize power consumption and some aspects of signal processing, compared to the more commonly used frequency-domain filter banks, but ultimately this complements the human auditory system and helps optimize sound quality. Combined with the highest sampling rate in the industry, which significantly reduces artifacts in the signal that would otherwise need to be fixed, this has enabled Widex to have a market-leading processing delay (2.5 ms on average), which was even further reduced with PureSound. In this article, we show how these two major innovations in sound quality – reduction of delay and individualized gain calculation – show effects across technical measurements, laboratory studies and real-life use.

THE PHYSICS OF DELAY AND WHY IT MATTERS

Processing delay arises in digital hearing aids because signal processing takes time, generally with average delays in the range from 5 to 8 ms (see left panel of Figure 1). This is well below the threshold where the auditory and visual signals become mismatched, so with an entirely closed ear mold, delay is not a problem. However, in open and vented fittings, it does become a problem, because the delayed amplified signal mixes with the direct sound that reaches the eardrum through the venting, resulting in an audible artifact known as comb-filtering. This arises because the two sound sources are out of sync and in turn add up or cancel each other out, making the gain-frequency curve resemble the teeth of a comb (see right panel of Figure 1). The perceptual experience is a tinny, artificial sound.

The problem of delay is not an easy one to fix, because processing necessarily takes time. It is also not a problem that the hearing industry has focused on solving, possibly due to a consensus that delays below 10 ms are tolerable (Stone & Moore, 1999, 2002, 2003, 2005; Stone, Moore, Meisenbacher, & Derleth, 2008). However, "tolerable" sound is not the same as ideal sound, so Widex developers set out to reduce delay, taking advantage of the Widex choice of a time-domain filter bank and high sampling rate to create a signal-processing pathway with mean delay below 0.5 ms. The result is a smooth gain-frequency curve (see blue line in

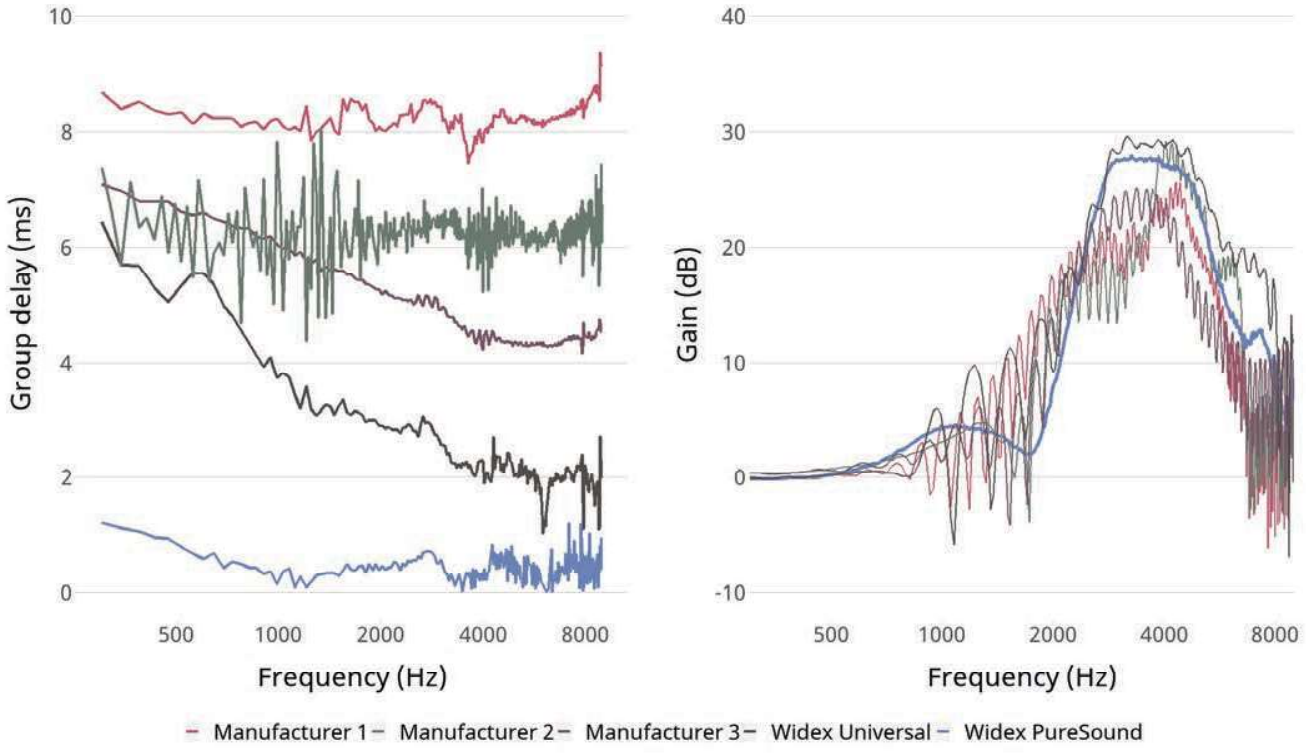

Figure 1: The left panel shows group delay by frequency for five top hearing aids, while the right panel shows the comb-filtering that is the result of the longer delays. For more detail, please see Kuk and Slugocki (2021)

Figure 1) and a natural sound without comb-filtering. This ZeroDelay™ signal processing is implemented in the PureSound program, which is targeted towards hearing aid wearers with mild-to-moderate hearing losses, who are likely to have the open and vented fittings where comb-filtering is a problem – and are also more likely to hear the improvement in sound quality.

Delay and Hearing Experience

The measurements illustrated in Figure 1 show a clear advantage for Widex PureSound, but a key question is of course how the signal-processing speed translates into the hearing experience of the wearers. To test this, we conducted a series of studies, investigating perceived sound quality, speech intelligibility in realistic conditions, and neural response using EEG.

In a guided walk study (Balling, Townend, Stiefenhofer, & Switalski, 2020), we included 21 participants: 13 in the PureSound target group of new and experienced hearing aid users with mild-to-moderate hearing loss, and eight with normal hearing in order to gauge the similarity between PureSound and unamplified sound. Participants indicated their preference for PureSound vs. standard delay processing in 20 different scenarios, including listening to speech in quiet and different types of noise, to own voice, to different ambient noises and to specific sounds in the environment. In all scenario types, the majority of preferences were for PureSound, and there were overall significantly more preferences for PureSound compared to standard delay. Most strikingly, 85% of participants with hearing loss and 100% of normal-hearing participants indicated an overall preference for PureSound.

In short, the research showed a clear sound quality preference for PureSound. However, it remains important to verify that this preference does not come at a cost of reduced speech intelligibility, also because, in order to keep delay ultralow, PureSound operates with an omnidirectional microphone. This choice is justified by the fact that the SNR improvement resulting from directional processing is low for the open and vented fits for which PureSound is appropriate (e.g. Magnusson, Claesson, Persson, & Tengstrand, 2013).

Speech intelligibility was investigated using the repeat portion of the Quick Repeat-Recall test (Quick RRT), testing three realistic signal-to-noise ratios (Kuk, Ruperto, Slugocki, & Korhonen, 2020). The test compared PureSound to top-of-the-line hearing aids from two other manufacturers that include directional processing. The results for 21 participants

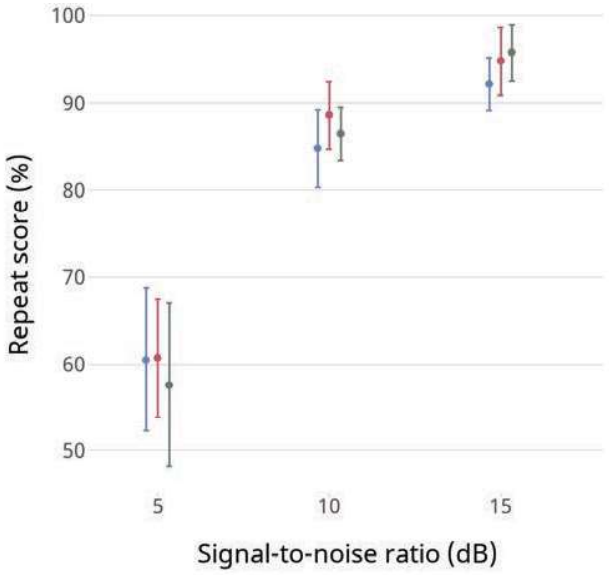

Figure 2: Repeat score from the Quick RRT. Circles represent the mean score, with error bars indicating 95% confidence intervals.

with mild-to-moderate hearing loss are illustrated in Figure 2 and show no significant differences between the three types of processing in any of the three realistic SNR conditions.

Together the two results show the PureSound program to have superior sound quality, with speech understanding on par with other leaders in the industry. To further understand these results, an EEG study (Slugocki, Kuk, Korhonen, & Ruperto, 2020) compared PureSound with the same two hearing aids as in the Quick RRT study, which have delays of 8 ms (Manufacturer 1) and 5 ms (Manufacturer 2). This study focused on the envelope-following response (EFR), the neural representation of the stimulus envelope, which should be more robust for less distorted signals. This is exactly what Figure 3 shows: The envelope of the /da/ stimulus in red is much more clearly matched by the neural envelope-following response for PureSound (top panel), while the EFR is distorted for the other hearing aids.

A more accurate neural representation of the envelope has been associated with more robust speech comprehension (Song, Skoe, Banai, & Kraus, 2011); thus, the EFR advantage for PureSound signal might contribute to the performance on the Quick RRT. Similarly, a more faithful neural representation may also contribute to the sound quality preference for PureSound observed in the guided walk study.

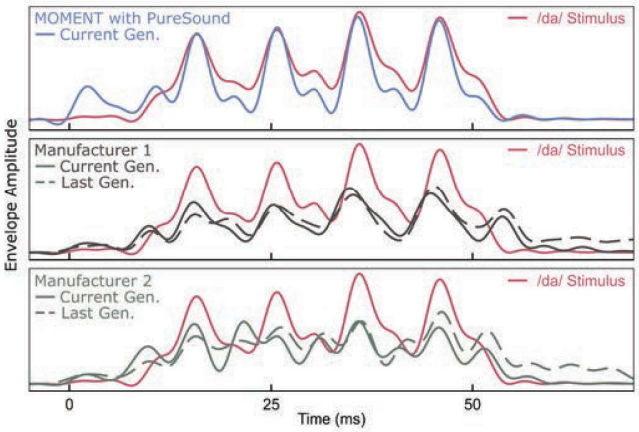

Figure 3: Envelope-following response for PureSound, compared to Manufacturer 1 (average delay 8 ms) and Manufacturer 2 (average delay 5 ms).

Individual Variation in Gain with Instant Ear Tips

While PureSound processing is ideal for individuals with mild-to-moderate hearing losses, the MOMENT platform is focused on sound quality for all hearing aid users, not just for this group. One particularly important consideration throughout the hearing loss range is the choice of ear tip and how this interacts with the acoustics of the individual wearer's ear canal.

As a basis for understanding this – and developing appropriate solutions – we conducted a large-scale study of how instant ear tips affect the gain at the eardrum with real-ear measurements for 58 ears (Balling, Jensen, Caporali, Cubick, & Switalski, 2019). Among other things, the study measured the vent effect (VE), the difference in real-ear aided response (with streamed sound) between a setup with just the hearing aid in the ear and a setup with the hearing aid in the ear and the ear completely occluded with impression material. This comparison indicates how much of the amplified sound escapes the ear.

The results are shown in Figure 4. The top left panel shows the average VE for all instant ear tips, which occur in the order that we would expect, with the open ear tips (red) showing the largest VE and the double domes (gray) the smallest. What is more interesting, however, is the variation between individual wearers that becomes apparent when considering each ear tip individually in the remaining panels. For each ear tip, there is substantial variation between individual ears, indicating that the amount of amplified sound "escaping" through the vent varies substantially between individuals. This applies to all types of instant ear tips, but it is

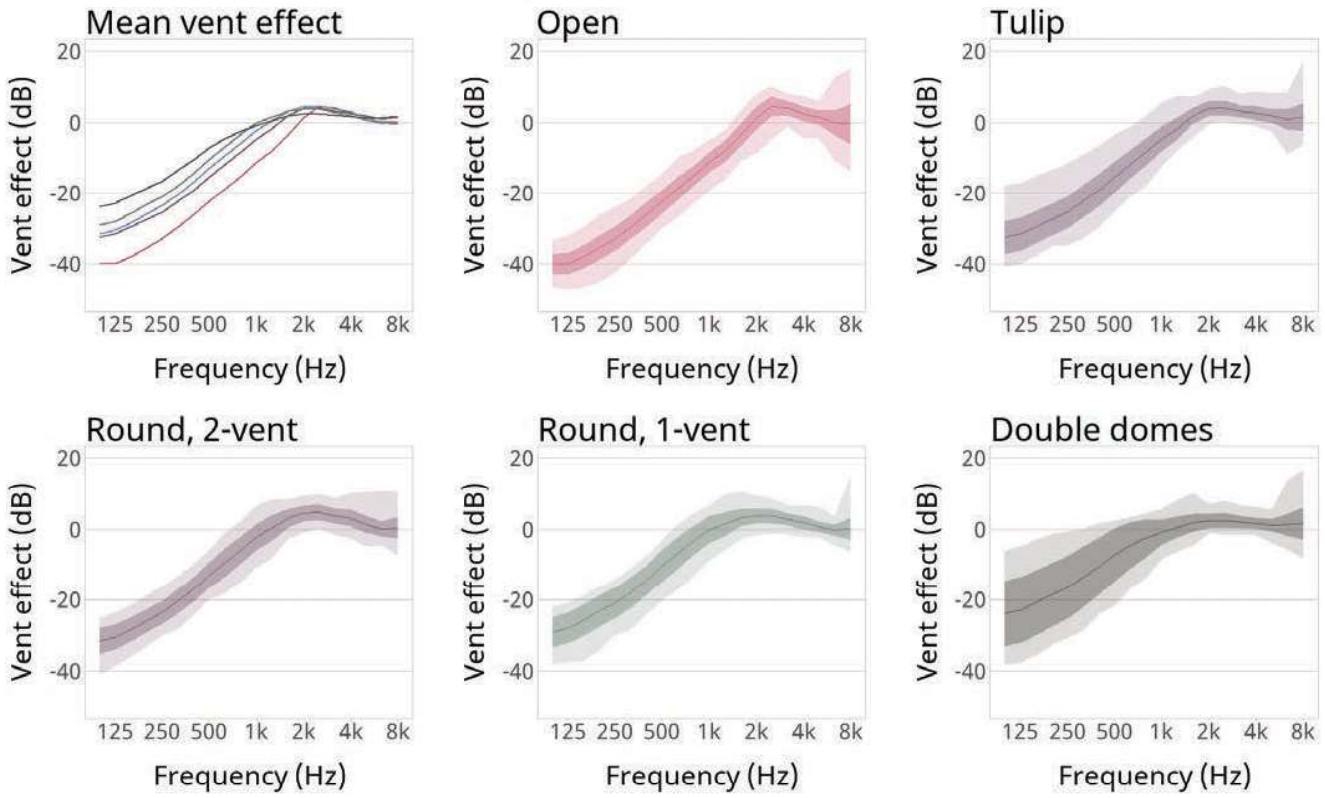

Figure 4: Vent effect measurements in 1/3 octave bands for different instant ear tips. The top left panel shows averages for all instant ear tips, the remaining five panels show mean (solid line), +/- 1 standard deviation (darker shaded area) and the full range of observed measurements (lighter shaded area).

particularly pronounced for the double domes, which are almost entirely occluded for some individuals and much more open for others.

The implication of these measurements for clinical practice is that the hearing care professional may choose an instant ear tip and expect it to behave in a certain way, but the individual fitting may give very different gain than expected. Given the results shown in Figure 4, this is expected to occur for many, if not most, instant ear tips, irrespective of brand. To avoid this problem and allow gain that is individualized to each hearing aid user, the Widex TruAcoustics fitting algorithm uses the feedback test to estimate the vent effect in the individual ear canal and adjust the gain accordingly. This results in a precise individualized fitting, where gain is not only adjusted to audiometric thresholds, but also to the specific anatomy of the individual wearer's ear canal. Correct calculation of gain for soft, normal and loud input is of course central to an accurate and natural sound.

Sound experiences in real life

While measurements and study results like the ones reviewed here are important, and we do all we can to make them as relevant to real life as possible, it remains crucial to also gauge the experience of hearing aid wearers in their daily lives. To this end, we conducted a survey of 101 experienced hearing aid wearers who tried out the Widex MOMENT hearing aids in normal use (Balling, Townend, & Helmink, 2021). The hearing aid wearers were fitted with MOMENT hearing aids and answered a range of questions about their experiences with both their own existing hearing aids and the MOMENT hearing aids. The Widex emphasis on sound quality should result in high ratings of sound quality satisfaction and naturalness for the MOMENT hearing aids, which is exactly what we see in Figure 5.

The left panel shows the degree of satisfaction with the sound quality of the hearing aids, with a significantly different distribution of ratings for own hearing aids compared to the MOMENT hearing aids. If we translate the satisfaction into scores from 1 to 7, the mean satisfaction is 6.0 for the MOMENT hearing aids, corresponding to a mean rating of 'Satisfied'. For own hearing

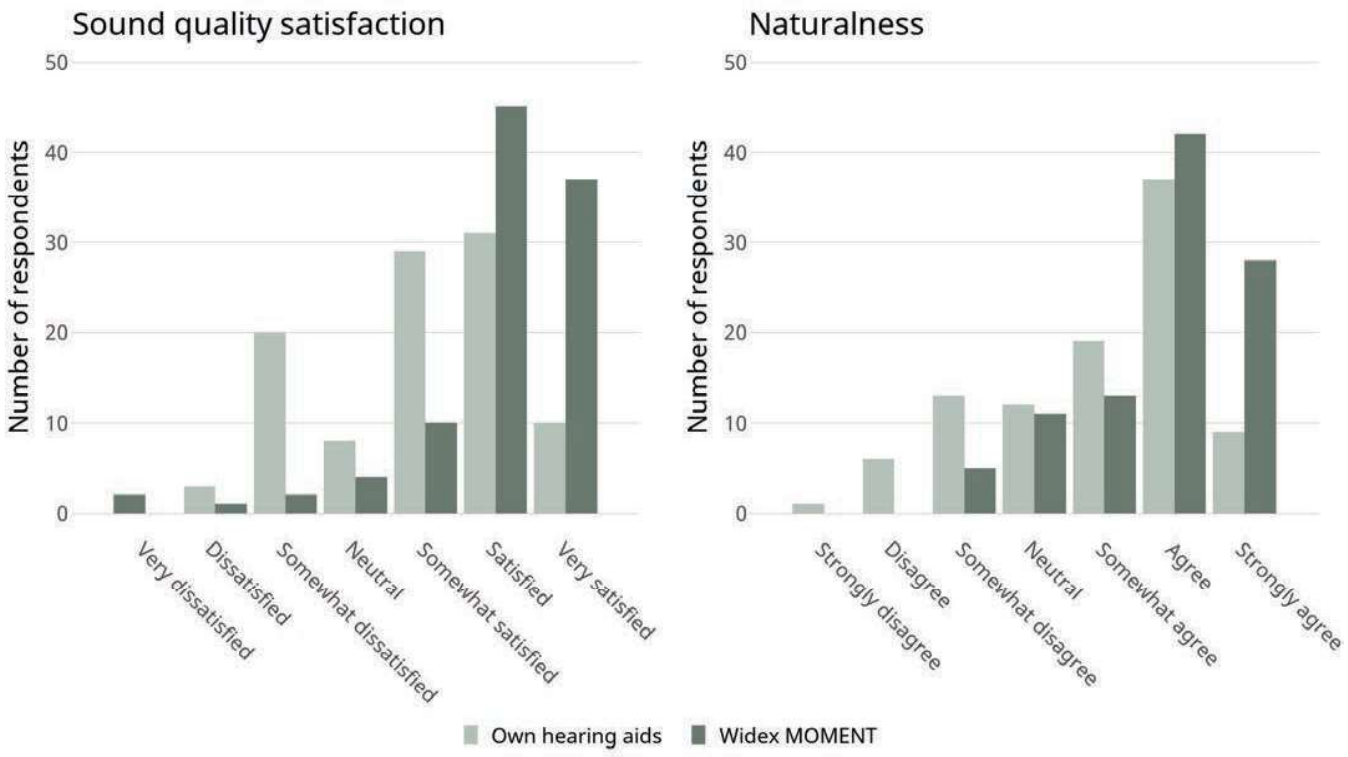

Figure 5: Ratings of sound quality satisfaction and naturalness from 101 experienced hearing aids users for their own hearing aids and Widex MOMENT.

aids, the mean is 4.9, corresponding to a mean rating just below 'Somewhat satisfied'. Focusing on the high end of the scale, the number of wearers who are very satisfied with the sound quality is almost four times as high for MOMENT as for own hearing aids. All in all, 91% indicate that they are satisfied with the sound quality of MOMENT.

The right panel shows the respondents' agreement with the statement "I find that sounds are natural with my own hearing aids/ the Widex MOMENT hearing aids." Again, we see a significantly different distribution of answers, with a mean rating of 5.8 for MOMENT and 5.0 for own hearing aids. This difference is particularly striking in view of the fact that the hearing aid wearers are habituated to their own hearing aids, and as such could be expected to find them more natural.

The high sound quality ratings are undoubtedly partly a result of the innovations in signal processing and fitting in the MOMENT hearing aids, but also a consequence of earlier design choices. To explore the development over time in more detail, a comparison between sound quality ratings in surveys of consecutive platforms of hearing aids is shown in Figure 6 (based on data from Balling et al., 2021; Balling, Townend, & Switalski, 2019; Kuk, Lau, Seper, & Sonne, 2016). This focuses on the top two ratings of 'Satisfied' and 'Very satisfied', and on those users whose own hearing aids were other brands than Widex. For all generations, the sound quality satisfaction is significantly higher for the Widex hearing aids, demonstrating the real-life effect of a design focus on sound quality. In addition, we see an increase in the proportion of respondents who are satisfied or very satisfied from platform to platform, with a particularly large jump from 2018 to 2020, which may be ascribed to the introduction of TruAcoustics in fitting and ZeroDelay processing in the PureSound program.

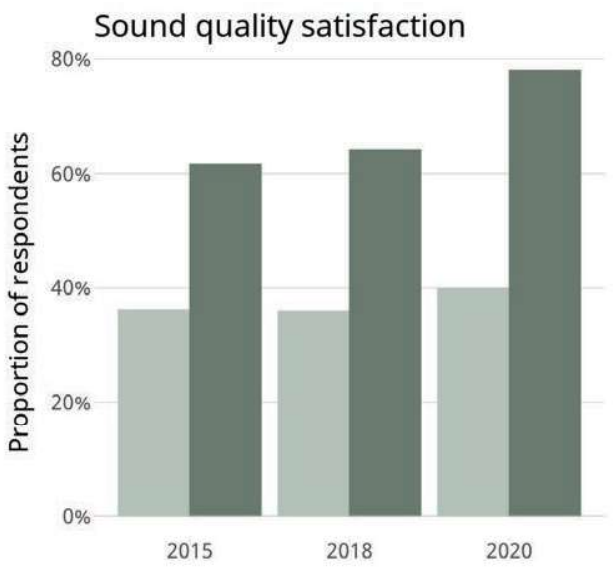

Figure 6: Sound quality satisfaction across generations of hearing aid platforms.

Conclusion

Building on decades of sound-quality focused development, the MOMENT platform enables sound to be handled differently depending on the hearing loss, with TruAcoustics adjusting gain to the acoustics of the individual's ear canal, and ZeroDelay processing virtually eliminating comb-filter distortion. These approaches optimize the signal for a truly individualized sound quality, showing clear advantages in technical measurements that translate into great individual hearing experiences in both lab studies and real life. ■

Laura Winther Balling *holds a PhD in psycholinguistics and has done extensive research on spoken and written language comprehension. She now works as an Evidence and Research Specialist at Widex.*

With more than 15 years in global product management, ***Dana Helmink, Au.D.*** *applies her experience in user-centered design to develop innovative educational experiences. She now works as the Sr. Director, Audiology/Clinical Education at Widex US.*

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