

WIDEX MOMENT™ – THIS SOUND CHANGES EVERYTHING

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Sound quality is synonymous with Widex, the hearing aids we manufacture, the components we build and the sound features we design. This is exemplified through multiple sound quality innovations. Some examples include ensuring undistorted input even at high levels (Oeding & Valente, 2015), providing sufficient amplification over an extended frequency range (Peeters *et al.*, 2011), and preserving sound's natural temporal characteristics with the use of slow-acting compression (Kuk, 1998). Every decision made in the process of bringing a new hearing aid to life finds us asking what the effect is on the final sound quality experienced at the ear. And, how Widex can ensure the highest standards in sound quality. This work is driven by a belief that a sound from a hearing aid that is more natural, untouched, unprocessed and analogous to the original leads to a more effortless listening experience (Kuk, 2017).

It is due to this uncompromising approach to sound quality that Widex continues to lead the field in bringing new standards in hearing to the market.

WIDEX MOMENT™ is, without a doubt, a revolution in sound, and this revolution is only possible because of our heritage. In this paper we will introduce the new sound that WIDEX MOMENT™ delivers, revisit the heritage that makes it possible, explain the innovation that makes it all happen, and look at the evidence that shows just how incredible this revolution is.

1. INTRODUCING WIDEX MOMENT™

A complete WIDEX MOMENT™ family has been launched with a new lithium-ion rechargeable RIC joining battery-powered RIC and ITE/ITC form factors. WIDEX MOMENT™ is built around a brand new platform designed for sound perfection, so that we now deliver the optimum next generation of Widex sound for all users.

With WIDEX MOMENT™ we take sound design in two directions: first the classic Widex sound inspired by our heritage and aspirations for good sound quality for all hearing losses. The classic Widex sound is delivered by the perfectly designed audiology engine with **TruAcoustics™** and market-leading delay. Next to that we are delivering the sound of the future, which we call **Widex PureSound™**. Widex PureSound™ is possible thanks to a second processing pathway: the **Widex ZeroDelay™** technology sound engine. Everything runs faster, is processed faster, handled uniquely and still delivered with the precision of Widex. WIDEX MOMENT™ breaks through poor artificial sound in fittings with open and vented ear tips for mild to moderate hearing losses, so the perfectly summed sound at the eardrum is always natural.

WIDEX MOMENT™ combines two pathways for different hearing losses, so we can offer truly customised and personalised sound rationales on one platform. These parallel, distinct approaches to amplification lead to increased sound quality and to greater sound acceptance, fitting outcomes and end user satisfaction.

2. TRUACOUSTICS™ - Great Sound for All

TruAcoustics™ is an intelligent algorithm by which the in-situ acoustics of the individual user's ear canal can be integrated in the parameter settings of the hearing aid, so that all processes and gain settings are optimised at first fit. TruAcoustics™ is active for all initial fittings – for both inexperienced and experienced users – and the target is natural, perfect sound. If you have less than optimal control of the in-situ acoustics, you risk (1) a perception of boominess and ultimately also (2) lack of high frequency gain. TruAcoustics™ calculates fittings more accurately than ever before and delivers perfect Widex processing.

2.1 TruAcoustics™ Development

Since 2006, Widex has been using an advanced way of estimating the acoustic effect of the ear mould and the true individual vent effect that affects the gain calculation for an individual hearing aid user. The method was called AISA (Assessment of In-Situ Acoustics). When the feedback test was done, AISA used a database to predict the vent leakage of the ear mould in the ear. In the development of AISA, we used the precise data from custom moulds built with the CAMISHA printer in our ear-mould lab. It was easy to predict the vent status based on measurements (feedback test), and the AISA algorithm looked up vent models in the vent model database to achieve the closest match for vent compensation (Kuk & Nordahn, 2006).

AISA was an accurate model until the entrance of instant ear-tips and open fittings. As part of our development project, we looked at how gain was summed for all our current moulds and ear-tip solutions. While custom moulds and custom ear-tips are very consistent in their acoustic properties, instant ear-tips are very much the opposite, with large variation between individual users in the amount of direct sound entering the ear. Research showed us that in instant fittings the vent leakage is not just defined by the type of ear-tip. It is just as much defined by the combined leakage in and around the instant ear-tip itself (Caporali *et al.*, 2019). RIC hearing aids accounted for 81.7% of all hearing aids dispensed in the first half of 2019 (Hearing Review, 2019) with instant ear-tips reported to be used in about 70% of fittings (Smith, *et al.*, 2008; Sullivan, 2018). As instant ear-tips are used in most hearing aid fittings, it is particularly interesting to understand the acoustic robustness and performance of these fittings. We looked at all available Widex instant ear-tips: open, tulip, round ear-tips and

double domes. Therefore, the classic AISA model has evolved in the WIDEX MOMENT™ family; through our research, we have developed a more intricate model that we call TruAcoustics™.

2.2 TruAcoustics™ Evidence and Effect

We conducted a large-scale investigation into the behaviour of Widex instant ear-tips, digging deep into how they behave and respond in terms of Insertion Loss (IL) and Vent Effect (VE). The published research (Caporali *et al.*, 2019, Balling *et al.*, 2019) is based on 58 ears and hundreds of measurements.

The measurements show very large variation in how much direct sound is transmitted through the ear-tip (IL) and how much sound escapes from the ear (VE). The VE results are illustrated in Figure 1. The figure shows large variation between the different ear-tips, which goes in the expected direction, with the open ear-tips showing the largest VE, followed by tulip, round and double domes. Secondly, and most importantly, there is also very large variation between different ears with the same ear-tip, indicated by the shaded areas in the figure. This variation is seen for all ear-tips but is particularly pronounced for the double domes, which may behave as almost entirely open or entirely closed.

Based on these measurements and comparisons between all the instant ear-tips, the custom earmoulds and the existing AISA model, we developed TruAcoustics™. As a result, the individual vent effect can now be estimated in a new and more precise way, leading to greater accuracy of fit, better sound and more precise recommendations throughout the fitting process. In other words, we have now replaced the AISA Transmission Line Model with a new statistical model for all instant ear-tips, thereby removing the source of overcompensation in lower frequencies so that boominess of own voice is gone.

Through the research into the in-situ acoustics of all the ear-tips, we also obtained better precision in the recommendation of instant ear-tips during acoustic selection in **COMPASS™ GPS**, and we confirmed the precision for custom earmoulds. This precision in ear-tip recommendation ensures the best premise to deliver appropriate gain. It is worth observing that while Widex strives to make the best predictions and recommendations, we still rely on the feedback test being completed to supply the Hearing Care Professional (HCP) and COMPASS™ GPS with the in-situ fit characteristics.

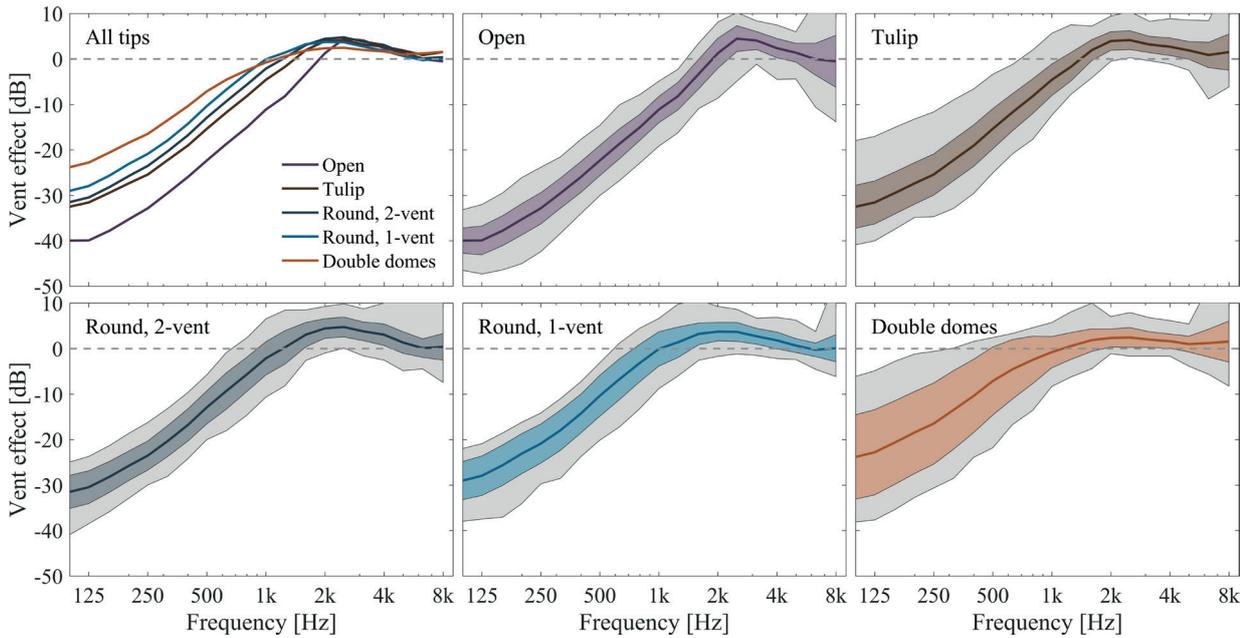


Figure 1: Average VE in 1/3 octave bands across 58 ears for the five ear-tips (top left). The other panels show the average VE per tip (thick coloured line) +/- 1 standard deviation (colour-shaded area). The light grey-shaded area represents the observed range of individual measurements.

2.3 TruAcoustics™ Summary

TruAcoustics™ is our best Widex fitting calculation and leads to our most natural sound for all Widex fits. Our new statistical model provides sound more accurately than before. TruAcoustics™ is an essential step in the personalisation and customisation of the perfect Widex sound, shaping the sound delivery to the exact properties of the individual acoustics in the ear canal and earware. Being the foundation of the fitting calculation means that TruAcoustics™ enables us to take another leap towards even more natural sound.

3. WIDEX PURESOUND™ AND WIDEX ZERODELAY™ TECHNOLOGY

Most hearing losses in the mild-to-moderate range are fitted with open or vented fittings. Widex PureSound™ is designed for these users as the innovative alternative to the classic sound design in our Universal listening program. Widex PureSound™ overcomes one of the biggest contributors to the artificial sound of open and vented fittings and one of the remaining challenges for mild-to-moderate hearing losses – the comb-filter effect. Widex PureSound™ presents a very different and more natural sound, where the transparent naturalness makes a perfect impression.

3.1 Comb-filter Effect

For open and vented fits, the direct sound that enters through and around the ear-tip mixes with the amplified sound at the ear drum. This results in a timing mismatch due to delay – the time it takes the hearing aid to process the amplified sound. This timing difference causes the comb-filter effect, where peaks and troughs form in the sound wave (Figure 2). In acoustic terms, we see constructive and destructive interference due to sounds mixing in phase adding together and sounds mixing out of phase cancelling each other out. The resulting sound quality has a tube-like quality to it, called the comb-filter effect, and once it is noticed, it can be very hard to accept.

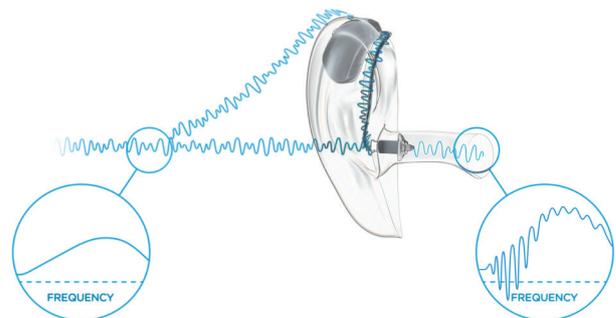


Figure 2: A schematic of the comb-filter effect as a result of the mixing of amplified and direct sound at the eardrum

The hearing aid wearer might call it a “tinny sound”. Currently this unfortunate sound artefact is one of the last major contributors to poor sound quality and is experienced to a varying degree in all commercially available hearing aids with non-closed ear tips. Even the low delay possible in modern hearing aids is enough to cause this negative effect. A recent study on sound quality in hearing devices states that “the processing delay of 6.5 ms causing comb-filtering effects, is the main limiting factor for sound quality” (Schepker *et al.*, 2019). Widex PureSound™, dramatically reduces the processing time through the hearing aid to below 0.5 ms, which means that the comb-filter effect is practically eliminated. By more perfectly matching the two sound sources, the experience is pure, natural, transparent and uncompromised.

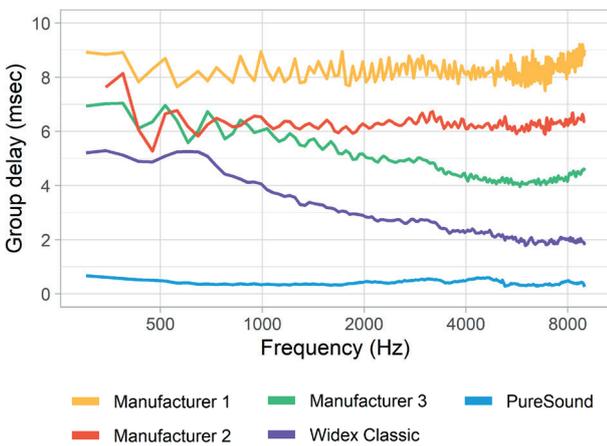


Figure 3: Graph illustrating the group delay for main manufacturers in the industry

Figure 3 shows group delay for different manufacturers. This clearly illustrates that Widex is already the market leader regarding group delay in our platform, while Widex PureSound™ is entirely in a league of its own. As a result, the WIDEX MOMENT™ platform is far better than any other brand in the market both in the Universal program and in the Widex PureSound™ program.

3.2 Widex Heritage – Always Lowest Delay

The entire hearing aid delay (group delay) relies on three stages: input, digital signal processing (DSP) and output stages. Widex has always designed and optimised every stage of the hearing aid to work efficiently for optimal sound quality.

INPUT: At the input stage, where we have led the market with true input technology, not only did we design A/D converters to deliver the largest linear input range in the industry; we also designed them to be ultra-efficient in terms of time delay.

DSP: We are the only manufacturer basing our signal processing core exclusively on a time-domain filter bank, allowing for extremely low delay and signal processing efficiency from the outset. All other manufacturers have built their filter banks in the frequency domain and consequently must live with the timing and delay constraints of such a design. Widex remains with a time-domain filter bank because it is the best premise for high-fidelity sound and offers the minimum time delay in processing.

OUTPUT: We can deliver an ultra-low delay output stage because of our input sampling rate of 33kHz. 33kHz was chosen as the Widex sampling rate because it maintained the maximum sound quality required by Widex design specifications. At the time, it was considered a design innovation as the Widex chipset was able to deliver this sampling rate with no detrimental effect on power consumption. It is vital in allowing our low group delay because a high sampling rate contains fewer artefacts, which in turn means less cleaning of the signal at the output stage, allowing for an ultra-low delay output stage.

Our classic sound pathway can amplify and process sound with greater speed than any other manufacturer – this gives a sound quality advantage for all fittings. Plus, with the WIDEX MOMENT™ platform we have made special efforts to further reduce delay in the DSP stage of the hearing aid to address the mild-to-moderate hearing loss categories with the Widex ZeroDelay™ pathway. Therefore, in the WIDEX MOMENT™ platform, sound is processed through one of two available pathways:

- The Widex Classic™ pathway on the WIDEX MOMENT™ platform, with heritage DSP features. In effect, all specialised signal processing algorithms are processing stages along the transmission line. A new stage, the Personal Gain Integrator, ensures perfect integration of all these differentials in perfect balance with TruAcoustics™ to ensure the perfection of individualised sound at the eardrum (see above section 2 on TruAcoustics™).

- The Widex ZeroDelay™ pathway on the WIDEX MOMENT™ platform, with adapted versions of all relevant heritage features to deliver the best sound with next to no comb-filter effect. As this pathway relies on fast delivery of sound, some features are altered in nature but are still targeting signal-to-noise ratio improvements and instant feedback control. The signal processing features in the Widex ZeroDelay™ pathway mirror the intent of the Widex classic features but adapt them to the faster engine and filter gearing. It is important to stress that operating with virtually no delay does effectively change the opportunity space for feature functionality.

Widex PureSound™ is a platform feature for WIDEX MOMENT™, which means it is available in all price points 110-440 and is a true alternative to our Universal program throughout the price-point range. The unique design of the Widex ZeroDelay™ pathway means that Widex PureSound™ includes a series of heritage Widex features (see features in Widex PureSound™ below).

Significant contributors to the performance of hearing aids including Widex PureSound™ are the channels, sound classes and other price point features. The granularity of analysis and processing is determined by channels and sound classes just as in previous families. And as always, the higher the granularity, the higher the specificity of processing.

Widex PureSound™ is available in all WIDEX MOMENT™ RIC products (and future BTE products) and promoted for open and vented fittings with appropriate hearing losses. COMPASS™ GPS will make a recommendation for Widex PureSound™ to be included in fittings for candidates within the fitting range for Widex PureSound™ shown in Figure 4. If the HCP follows this recommendation, the hearing aid will be set up with Universal (P1) and Widex PureSound™ (P2). The HCP can choose to reorder the hearing aid programs and/or set up GPS to do this by default. Widex PureSound™ operates as a substitute for Universal, but there may be situations where the more processed sound via Universal may be useful. It is therefore not possible to fit a hearing aid with Widex PureSound™ alone.

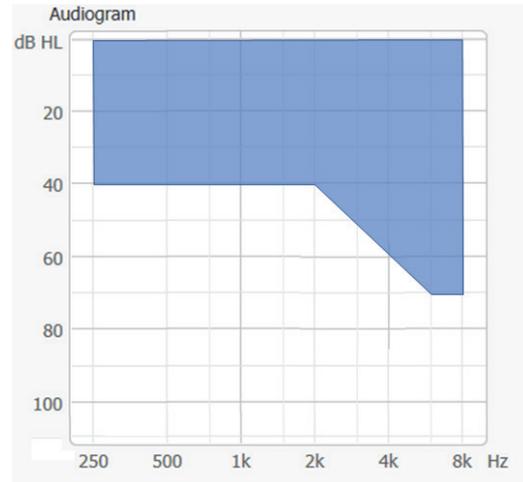


Figure 4: Fitting range for Widex PureSound™

3.3 Features Running in Widex PureSound™

The premise for Widex PureSound™ is a complete rethinking of how the best sound is designed for the mild-to-moderate hearing-loss group. We have questioned the status quo and made significant changes in how sound is processed and how to make real-life listening as pure and natural as possible. It requires rethinking of the logic in signal processing, and indeed the paradigm for all classic processing schemes has been re-evaluated to determine the optimal combination of advanced features. Widex PureSound™ is unique both for Widex and the hearing industry. It is a conscious decision by Widex to take sound quality to the next level with a new design inspired by science and innovation to deliver a tailored, purposeful sound. With Widex PureSound™, nothing is quite as it was; sound is more natural, swift and perfect.

As a result of this design innovation, three classic features are modified in the Widex PureSound™ processing. The dual-microphone adaptive directionality and the TruSound Softener both rely on extended delay in the signal pathway and are therefore not compatible with an ultrafast processing path. The Speech Enhancer is also not included in Widex PureSound™ because the time-consuming nature of this feature is counterproductive to the purpose of the new processing. In place of the Speech Enhancer, a dedicated customised noise reduction algorithm is applied. Speech intelligibility testing with WIDEX PureSound™ showed the program performed on par with the Universal program and leading competitors.



3.4 Evidence for Widex PureSound™

Figure 3 clearly shows that Widex PureSound™ is in a league of its own with respect to delay, practically eliminating the comb-filter effect and leading to a much more natural sound. However, the important question about this technical revolution is how it translates into user experience in real life. To investigate this, we conducted a series of scientific studies with Widex PureSound™, exploring sound quality in a range of real-life situations, speech intelligibility in realistic signal-to-noise ratios and neural response to speech.

Because the motivation for developing the Widex ZeroDelay™ pathway was sound quality,

this was our first focus in two studies. The first study (Balling *et al.*, 2020, see box A) was a sound quality guided walk with participants with hearing loss in the Widex PureSound™ range (both experienced and inexperienced hearing aid users) and participants with normal hearing. These participants compared two hearing aid programmes: Widex PureSound™ vs. a more standard hearing aid delay. They indicated their sound quality preference in a range of settings, including quiet and noisy surroundings, listening to speech and own voice. Across all situations we observed a clear Widex PureSound™ preference, and we saw that 85% of listeners with hearing loss and 100% of listeners with normal hearing preferred Widex PureSound™ overall.

BOX A: SOUND QUALITY GUIDED WALK

- 21 participants
 - 13 with HL (experienced and inexperienced HA users)
 - 8 with NH
- 2 HA programmes: Widex PureSound™ vs. standard delay, active features off
- HAs cluster fit to N2 (HL group) and flat 25dB (NH group)
- 20 sound comparisons: speech, own voice, ambient noise and specific sounds in 14 different environments.
- Participants indicating
 - Program preference in each situation
 - Degree-of-preference in each situation on scale from -3 to 3 (Figure 2)
 - Overall preference across entire guided walk (Figure 1)

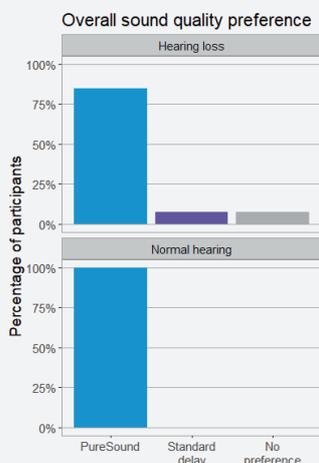


Figure 1: Overall preference indicated in exit interview for HL group (top) and NH group (bottom).

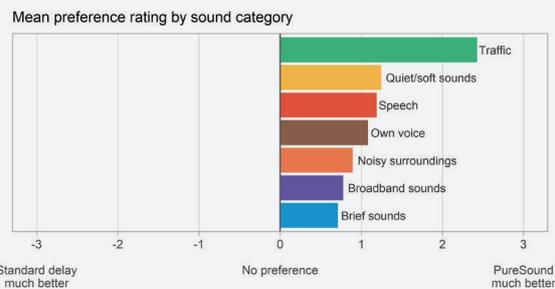


Figure 2: Degree-of-preference ratings in different types of situations. Mean preference for Widex PureSound™ for all types.

Results

- Significantly more Widex PureSound™ preferences
- Majority of preferences were for Widex PureSound™ in all situations
- Widex PureSound™ preference in all types of situations (Figure 2)
- 85% of participants with mild-to-moderate hearing loss prefer Widex PureSound™
- 100% of participants with normal hearing prefer Widex PureSound™
- Sound quality of Widex PureSound™ preferred by both experienced and inexperienced HA-users

Reasons given for Widex PureSound™ preference: Better voice quality, better understanding, calm, clear, less shrill, less noise, more detailed, more natural, more pleasant, more recognizable, no rushing/static, softer

Balling, Townend, Stiefenhofer, Switalski, Hearing Review, April 2020.

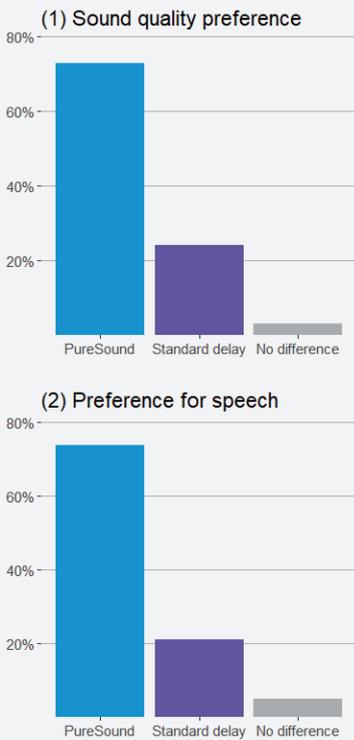
A similar pattern was observed in the second sound quality study (box B), which was a “Pepsi challenge” survey where 100 listeners who self-identified as normal hearing listened to the same two hearing aid programmes and indicated their preference. Both when listening to speech and when listening to the surroundings, a large majority of listeners preferred the Widex PureSound™ sound quality (73% general preference, 74% preference for speech), while the numbers for standard delay were only 24% and 21% respectively. Importantly, the improved sound quality observed in these two studies does not come at the cost of reduced speech intelligibility, as evidenced by

the study reported by Kuk *et al.* (2020), see box C. This study tested speech intelligibility in realistic signal-to-noise ratios of 5, 10 and 15dB and found that Widex PureSound™ with its omnidirectional settings performed on par with two other premium hearing aids that included directional microphones. These test conditions generalise to most situations the listener is likely to encounter, but for more challenging situations, the listener may change to Universal with directional microphones.

Finally, we investigated the neural response to sound with Widex PureSound™ compared to two premium hearing aids from other manufacturers (Slugocki *et al.*, 2020, box D). The study, which used electroencephalography (EEG), measured neural encoding of speech sounds when listening with different hearing aids. The study focused on the envelope-following response (EFR): the neural representation of the envelope of the speech sound and comparisons between the original stimulus envelope and the neural representation were made. The study showed a more faithful neural representation of the speech signal when listeners listened with Widex PureSound™, while the representation was more distorted for two other premium hearing aids. Since less distortion means less effort, this may contribute to a more effortless listening experience for Widex PureSound™ users, and the more faithful neural representation may also contribute to the improved sound quality experienced for Widex PureSound™.

BOX B: “PEPSI CHALLENGE” SURVEY ON SOUND QUALITY

- 100 respondents with normal hearing
- Many different locations: restaurant/cafeteria, outside, retail, sports venues
- 2 hearing aid programmes: Widex PureSound™ vs. standard delay, active features off
- 2 questions: (1) General sound quality preference, (2) Preference when listening to speech



3.5 Widex PureSound™ Summary

Widex PureSound™ is a revolution in sound for mild-to-moderate hearing losses. Widex has overcome one of the last major barriers to sound quality, and the resulting sound is preferred in testing, provides robust speech-in-noise performance and shows highly faithful neural encoding. The potential for Widex PureSound™ to allow new and existing users to experience the most natural sounds will lead to improved fitting experiences, easier hearing aid acceptance and overall increased hearing aid satisfaction.

BOX C: SPEECH INTELLIGIBILITY TEST

- 21 participants with mild-to-moderate hearing loss: 13 experienced and 8 inexperienced HA users
- Three hearing aids: Widex PureSound™ (< 0.5 ms delay) vs. Competitor A (8ms delay) vs. Competitor B (6 ms delay)
- Fit to NAL-NL2 with all features active: omni microphone for Widex PureSound™ (to keep delay low), directional microphones for Competitor A and B
- Quick RRT: Repeat low-context sentences in three realistic SNRs: 5, 10 and 15 dB
- Results show that speech comprehension with Widex PureSound™ is
 - On par with directional microphones of major competitors in realistic SNRs even though Widex PureSound™ uses omnidirectional microphone setting to keep delay ultralow
 - Within middle 50% of normal-hearing performance

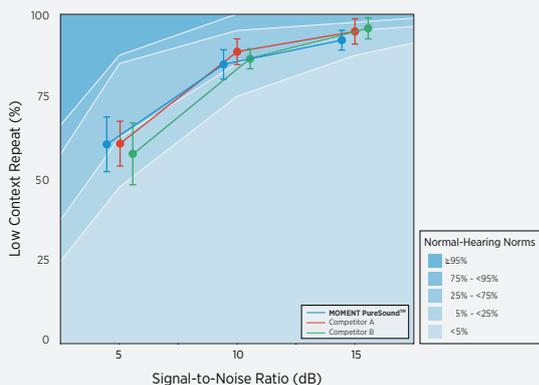
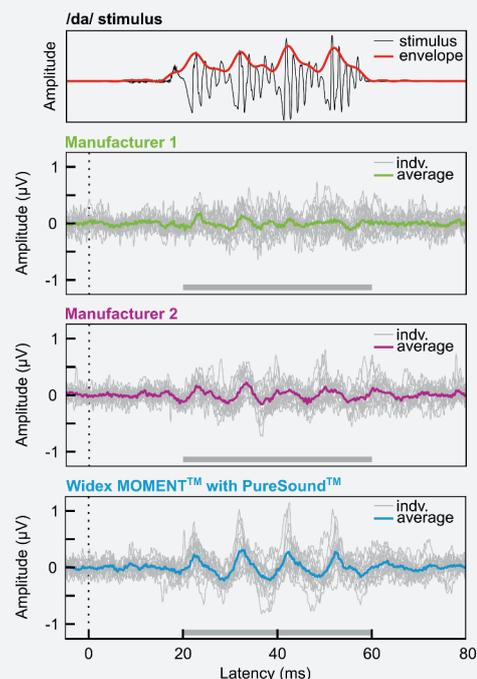


Figure 1: Repeat performance for low-context sentences with three different hearing aids in three SNR conditions. The shading in the background shows the performance of normal-hearing listeners on the same test, with the darkest shade showing the highest-performing 5% and the lightest shade the lowest-performing 5%.

Kuk, Ruperto, Slugocki, Korhonen. Hearing Review, June 2020

BOX D: NEURAL ENCODING WITH WIDEX PURESOUND™

- 16 participants with mild-to-moderate hearing loss (subset of participants from box C)
- 3 hearing aids: Widex PureSound™ vs. Competitor A vs. Competitor B (see also box C)
- EEG-study measuring neural encoding of speech sounds when listening with different hearing aids
- Stimulus: 8000 repetitions of synthesised /da/ syllable presented in free field
- Focus on envelope-following response (EFR): the neural representation of the envelope of the speech sound, comparing stimulus envelope to the neural representation for each of the three conditions.
- Results
 - EFR for Widex PureSound™ (bottom panel) clearly most similar to envelope of actual stimulus (top panel)
 - Distorted EFRs for competitor hearing aids (middle panels)
 - Significantly more robust neural encoding of envelope for Widex PureSound™ than for both competitors



Slugocki, Kuk, Korhonen, Ruperto. Hearing Review, August 2020



4. WIDEX MOMENT™ SUMMARY

WIDEX MOMENT™ is a truly remarkable hearing aid. A leap forward in sound quality for open and vented fittings, WIDEX MOMENT™ addresses mild-to-moderate hearing loss via a distinct processing pathway. For all hearing losses TruAcoustics™ takes our Widex classic processing sound quality further with a more personal and accurate fitting model. The beauty of the WIDEX MOMENT™ platform lies in the fact that two processing pathways run parallel to each other, synchronous and both with automated features. Countless users will see benefits in both processing styles, and WIDEX MOMENT™ allows for both processing pathways to be easily switched, delivering the best of both worlds of sound quality.

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