DNN 360 for Dual Microphone Custom Devices

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Key takeaways:

- DNN 360 for customs brings DNN-powered directionality to custom ITC and ITE devices by optimizing the model for their unique acoustic design.
- The training-data methodology uses controlled variation in microphone geometry, acoustic scenes, speech locations, and sound types to promote stable network behavior across diverse custom product configurations.
- DNN 360 for custom devices was found to significantly decrease listening effort compared to Legacy Directionality.

Introduction

Audibel's flagship innovation, DNN 360, represents an industry-exclusive advancement in multi-channel deep neural network (DNN)-driven directionality. Combining DNN Directionality with DNN Spatial Awareness, it is engineered to optimize the balance between focused listening and environmental awareness. This enables hearing aid users to participate naturally in conversations while remaining attuned to their surroundings. DNN 360 is now integrated into dual microphone custom styles within the Aris AI+ portfolio, further enhancing performance in discrete form factors.

Custom hearing aids present a different engineering problem than receiver-in-canal products. In custom dual microphone in-the-canal (ITC) and in-the-ear (ITE) devices, the final microphone geometry is shaped by shell size, faceplate orientation, and manual assembly processes. Those mechanical differences change the acoustic relationship between the two microphones and can shift the inter-microphone magnitude and phase cues that directional algorithms depend on.

A DNN intended for customs therefore cannot be trained only on nominal geometry; it must be trained on the distribution of device conditions that are reflective of real-world variations.

DNN 360 for custom hearing aids addresses that challenge by retraining DNN Directionality for custom form factors and carrying the resulting model into DNN Spatial Awareness.

The goal is to deliver the same flagship feature set across product styles to benefit from better hearing in diverse listening environments. To achieve this goal, custom variation is not treated as a late-stage exception, but the DNN training-data methodology treats it as a first-class design input.

System Overview

Audibel's DNN Directionality was designed to intelligently apply the most appropriate directionality patterns that adapt in real time to complex and dynamic soundscapes that hearing aid users might encounter *(Marquardt et al., 2025)*.

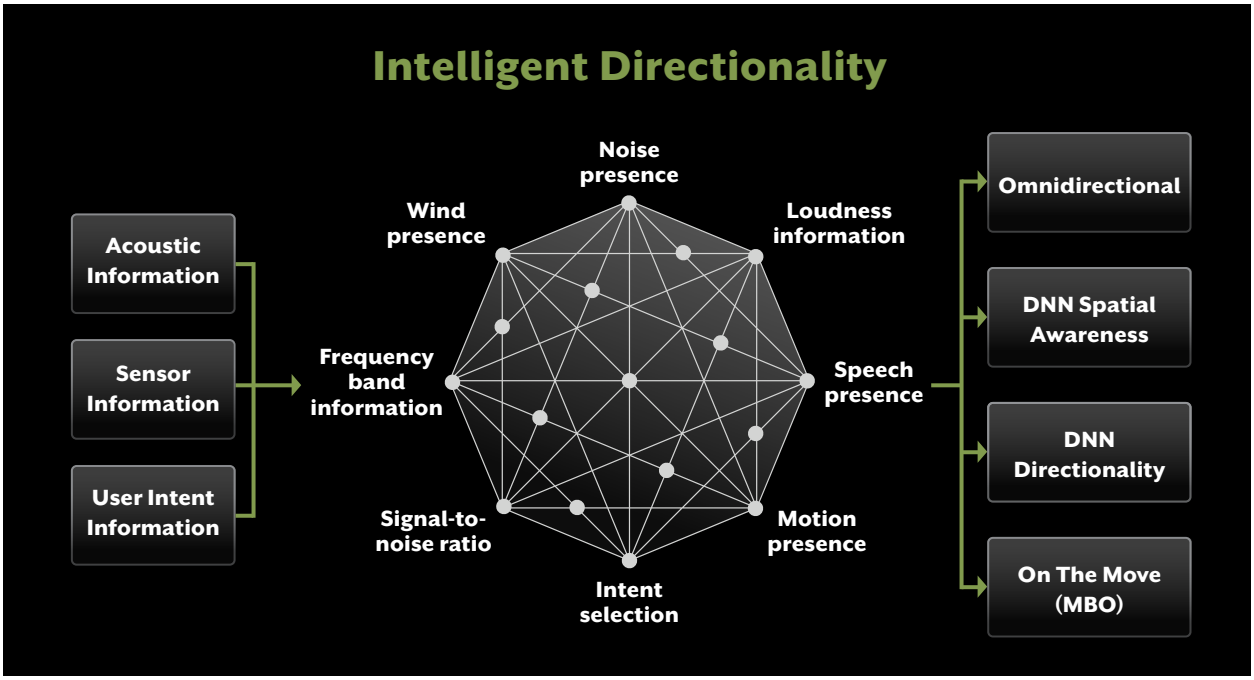

Figure 1: A schematic representation of Audibel's intelligent directionality system.

DNN Spatial Awareness builds on the same design and is trained to improve audibility of short speech events, greeting words, and relevant environmental sounds in noise while automatically switching to a speech-focus mode when sustained conversation is present. Because the current DNN Spatial Awareness implementation depends internally on DNN Directionality, the two features are coupled for custom products as well: DNN Spatial Awareness is available when DNN Directionality is enabled on supported dual microphone flagship devices. These work together with the other systems to intelligently provide the listener with the most appropriate settings for the environment that they are in *(Figure 1)*.

Training-Data Methodology

Since every custom hearing aid has slightly different microphone placement and acoustic characteristics, the DNN Directionality was retrained using data that reflects the real-world variability found across custom products. The starting point is the training-data methodology of the proven RIC implementation, but is extended for custom form factors such that learning reflects the microphone transfer functions of dual microphone ITC and ITE products.

A practical training-data corpus for DNN 360 spans both acoustic variability and product variability. The methodology used to create that corpus is as follows. First, multi-microphone impulse responses of custom dual-microphone devices are measured on head-related geometries. This captures form-factor and fit-dependent transfer functions to the front and rear microphones, including placement variants representative of manufacturing tolerances.

Second, those device responses are combined with room impulse responses generated across a large set of simulated acoustic environments (on the order of hundreds of room configurations, each with multiple source and listener positions).

Third, speech and noise material is drawn from multiple speech and noise databases and convolved onto all microphones of the bilateral dual-microphone array to synthesize virtual multi-

channel recordings. To capture realistic variations in the hearing aid wearer's environments, noise fields include discrete directional interferers, close-to-diffuse multi-channel fields, and multi-talker babble. Directionality-specific dual-talk cases are also included, with frontal target speech preserved and rear interfering speech treated as a suppressible interferer.

Fourth, spectral and spatial features are computed from the synthesized multi-channel mixtures. The representative training sets produced by this pipeline are in the order of hundreds of hours of multi-channel audio. This combination of acoustic diversity and product variability is what enables the network to learn and generalize across expected product variation.

Capturing Variability

The multi-mic device responses used for training are obtained from anechoic Knowles Electronics Manikin for Acoustic Research (KEMAR) measurements of custom hearing aids on a dense spherical grid of source directions (on the order of ~600 azimuth/elevation angles). For each fitted device, bilateral dual-microphone impulse responses are recorded at the adjacent microphones of both left and right instruments, yielding a full-sphere 3D multi-mic Hearing Aid Related Impulse Response (HARIR) dataset *(Figure 2)*. Multiple physical devices and repeated ear-canal seatings are included so that placement and shell geometry variation representative of manufacturing and fit is captured in the data. Left- and right-side measurement sets are then combined and used by the training-data pipeline; room effects are applied later by offline room augmentation rather than during the free-field KEMAR sphere capture.

Because custom dual-microphone devices exhibit placement-dependent front–rear magnitude and phase relationships, the training and validation

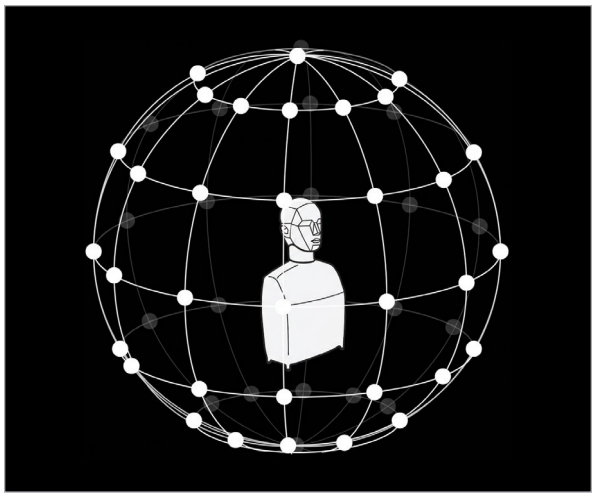

Figure 2: Depiction of the various measurements and angles that were performed to validate the retaining of custom technology with DNN 360.

strategy must explicitly cover the variability of customs rather than a single nominal build. To quantify that variability, a response-surface experiment was performed on customs devices using a Box–Behnken design with three manufacturing factors identified from custom assembly practice: faceplate rotation from –10° to +10°, shell protrusion from –5 mm to +5 mm, and surfacing angle from –15° to +15°. This enables the inclusion of realistic and measured variability that can be propagated into the training-data and for robustness testing rather than relying on anecdotal evidence about manufacturing variability.

The analysis showed that the sensitivity of the dual-microphone relationship is frequency dependent. Level differences between the microphones were largely stable at 1 kHz, weak and noisy at 2 kHz, and most affected at 4 kHz where rotation produced roughly plus or minus 1.0 dB mismatch. Phase differences showed a different pattern: all three factors mattered at 1 kHz with modeled responses spanning about 8.5 microseconds to 22.8 microseconds, shell protrusion dominated at 2 kHz with rotation contributing a smaller secondary effect, and no factor was clearly dominant at 4 kHz.

These results provide a concrete target for how custom-specific perturbations should be represented in training and verification.

The measured variations described above are incorporated directly into training and validation. By exposing the DNN to the range of microphone relationships expected across custom products, the model learns to maintain stable directional behavior despite the variability inherent to custom manufacturing. As a result, DNN 360 can generalize across ITC and ITE devices without requiring device-specific tuning, providing a robust foundation for real-world performance.

This approach is also aligned with the broader advantage of DNN-based control described in Audibel's recent directionality work *(Figure 2, Marquardt et al., 2025)*. Traditional real-time estimation from instantaneous microphone statistics can fluctuate even in nominally static scenes, while a DNN trained on a broad dataset can directly predict the most appropriate control state for the current environment *(Figure 3)*. For custom devices, broadening the dataset to include product variation is what makes that stability credible in the final device.

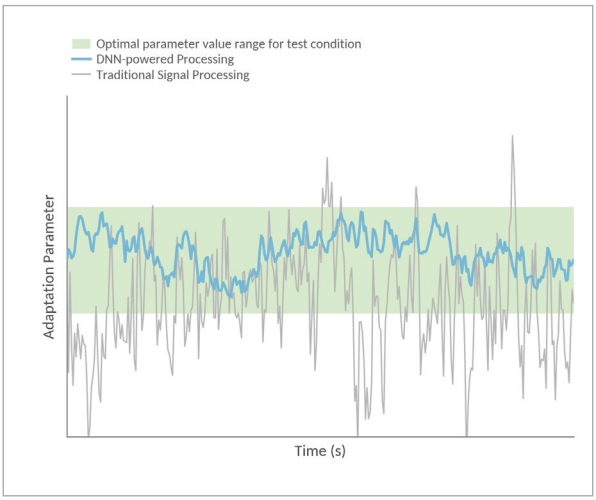

Figure 3: Example depiction of the differences between traditional estimation methods (gray line) versus a DNN-powered model prediction approach (blue line) in a laboratory measurement using Aris AI+ custom devices. The figure demonstrates the advantages of the DNN-powered processing in its ability to better predict the most optimal parameters (shaded green area) for a given situation.

Clinical Evaluation

Fifteen participants were fitted with Audibel Aris AI+ 24 ITE R and ITC R hearing aids using coupling configurations appropriate for their hearing loss and ear anatomy. Users had symmetric moderate to severe sensorineural hearing loss *(Figure 4)* and ranged from 34 to 86 years (M = 69; SD = 13.1). Seven participants were female. All participants had prior experience wearing hearing aids and were familiar with their use in daily listening environments. Each pair of hearing aids was programmed using the e-STAT 2.0 fitting formula and verified with an AudioScan Verifit 2 system. Following any necessary fine-tuning, participants wore the hearing aids in real-world listening environments for one month. After the trial period, a laboratory-based listening effort task was conducted.

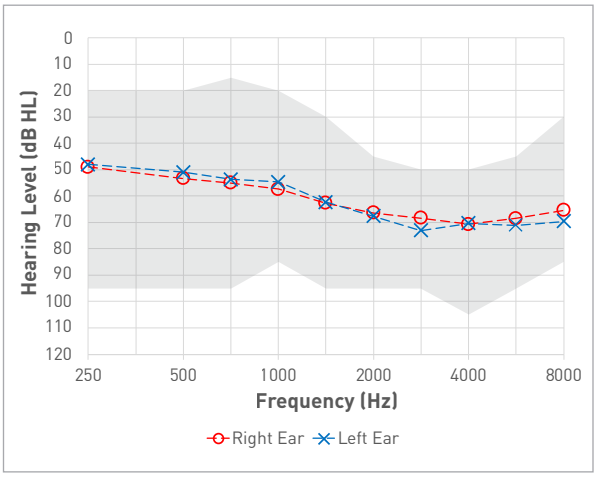

Figure 4: Average audiogram of 15 participants evaluated. Red (circles) and blue (crosses) dashed lines and symbols show the average hearing levels for the right and left ears respectively, with the range denoted by the shaded gray area.

Participants completed a listening effort task using the Adaptive Categorical Listening Effort Scaling *(ACALES; Krueger et al., 2017)* procedure while seated in a sound booth. During each trial, participants listened to speech presented in diffuse noise and rated their perceived listening effort on a 13-point scale ranging from 1 (no effort) to 13 (extreme effort).

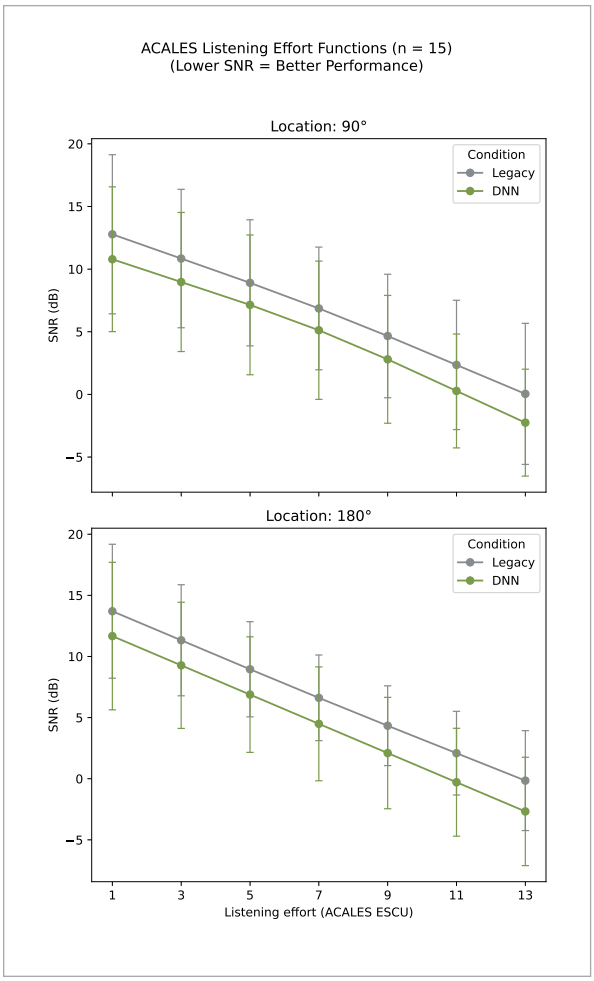

Figure 5: Mean SNR required to achieve each ACALES listening effort category for DNN 360 (DNN) and Legacy Directionality (Legacy). Lower SNR values indicate better performance, reflecting the ability to maintain the same perceived listening effort in more challenging noise conditions. Error bars represent ±1 standard deviation. ESCU: effort scale categorical unit.

Testing was conducted under two directional processing conditions, DNN 360 and Legacy Directionality, with target speech presented from either 90° or 180° azimuth. Participants were blinded to all processing conditions, and test order was counterbalanced. A linear mixed-effects model was used to evaluate the effects of directional processing. Results demonstrated a significant listening effort benefit for DNN 360 compared to Legacy Directionality. Across the full ACALES scale, participants were able to tolerate approximately 2 dB poorer signal-to-noise ratios (SNRs) while reporting the same level of listening effort when using DNN 360 ($p < 0.001$). This advantage was observed across all evaluated listening effort categories and was consistent across both target locations.

Post hoc analyses showed significant benefits for DNN 360 at every listening effort level tested (all $p < 0.001$), with improvements ranging from approximately 1.9 to 2.3 dB SNR. The consistency of these findings across effort levels demonstrate that DNN 360 can reduce listening effort in challenging listening environments compared to Legacy Directionality.

Conclusion

DNN 360 for Customs is not simply a part of a successful RIC feature into a new shell. It is a custom-domain adaptation problem whose success depends on how well the training data captures the acoustic and manufacturing realities of ITC and ITE devices. The combination of custom-form-factor retraining based on a quantified microphone-variation enable a well-grounded path to bringing DNN Directionality and DNN Spatial Awareness to custom devices without sacrificing robustness.

The central lesson is that robustness is through a first-class input to the dataset in the dataset. By varying training data across measured microphone-position differences, acoustic scenes, speech locations, and sound classes, the DNN learns to make stable control decisions over the range of devices that will exist in the field. That data-centric approach is what allows DNN 360 to support a broader customs portfolio while preserving the performance expectations set by Audibel's flagship platform.

These findings were further strengthened with the clinical validation results that showed significant listening effort benefit compared to Legacy Directionality.

Acknowledgements

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Author Biographies

Deepak Kadetotad received his BE degree in electronics and communication engineering from MSRIT, Bengaluru, India in 2013, and his PhD degree in electrical engineering from Arizona State University in 2019. In 2019, he joined Starkey, where he currently works as a Senior Machine Learning Engineer. His research interests include application of machine learning and neuromorphic algorithms on energy-constrained hardware.

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Sian C. Halvorsen, Au.D., CCC-A, joined Starkey in 2023 as a Research Audiologist. She earned her B.S. at the University of North Texas and her Au.D. at the University of Arkansas for Medical Sciences. Her work at Starkey covers product and feature validation of hearing aids and accessories prior to market release, ensuring patient needs are being met and clinically relevant outcome measures are used.

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