

Edge Mode Evolution: Clinical Evidence for DNN-Enhanced Listening Comfort and User Preference



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Key takeaways:

- Users preferred the DNN enhancements in Edge Mode Reduce Noise.
- Edge Mode Reduce Noise demonstrated significantly greater comfort in diffuse noise compared to Personal program.
- Edge Mode Enhance Speech produced significantly lower listening effort ratings than both Personal program and Edge Mode Best Sound.
- Individuals with moderate to severe QuickSIN SNR Loss experienced significantly greater benefit from Edge Mode Enhance Speech than those with normal to mild SNR Loss.

Introduction

Edge Mode is Starkey's advanced AI-powered listening enhancement feature, leveraging onboard deep neural network (DNN) technology to optimize speech intelligibility and listening comfort in particularly challenging acoustic environments. At its core, Edge Mode is designed to give hearing aid users greater control over their listening intent. While many hearing aid systems rely exclusively on automated decision-making processes to decide on the best settings, Starkey recognizes that listening goals and preferences can vary from moment to moment. Edge Mode empowers users by providing selectable options that enable additional personalization of performance based on their immediate listening needs and environment.

When Edge Mode was first introduced in 2020, it functioned as a user-activated listening enhancement feature. Hearing aid users were counseled to activate Edge Mode when needed and then disable it when leaving that environment,

allowing the hearing aids to return to their standard automatic processing, which was generally more appropriate for everyday listening.

Subsequent enhancements enabled Edge Mode to automatically adjust its more aggressive processing once activated, allowing the feature to remain engaged for longer periods, even as listening conditions change, a feature referred to as Automatic Edge Mode.

Automatic Edge Mode is particularly effective in highly dynamic listening environments, where more targeted adjustments can selectively prioritize speech or listening ease to improve overall listening experience. In its default automatic setting, Best Sound continuously optimizes hearing aid parameters in real time based on the acoustic environment. The "Enhance Speech" setting is designed to focus processing power on improving speech intelligibility, while Reduce Noise is designed to prioritize listening comfort.

Since its initial release, clinical evidence has consistently demonstrated its effectiveness in enhancing speech intelligibility and listening effort benefits (*e.g.*, Jaekel & Xu, 2023 4b). Building on this foundation, the next generation Edge Mode introduces two enhancements: 1) an enhancement to the DNN algorithm to deliver superior performance, offering improved listener-preferred outcomes targeted at listening comfort, and 2) the ability to have Always-on Edge Mode when the hearing aid is powered on.

The aim of this enhancement was to provide clearer speech and superior noise reduction in the most challenging listening environments. To achieve this, the Reduce Noise setting leverages an enhanced DNN algorithm that was trained using additional soundscapes of a rich array of real-world, multilingual sound samples.

The goal of Always-on Edge Mode is to give hearing care professionals an additional fitting option for patients who frequently encounter challenging listening environments and regularly benefit from Automatic Edge Mode activation. Rather than serving as a default setting for all hearing aid users, the feature is intended for individuals whose daily listening demands warrant continuous access to enhanced signal processing strategies. Not all hearing aid users will prefer to have this feature enabled, reflecting differences in listening needs, lifestyle, and personal preference.

This white paper encompasses the results of two sections: an evaluation of the Edge Mode Reduce Noise setting and an evaluation of the Edge Mode Enhance Speech setting.

Edge Mode Reduce Noise Evaluation

Multiple studies were carried out to evaluate the outcome of the enhanced DNN algorithm implemented in the Edge Mode Reduce Noise setting. These included assessment of (1) listener preference in speech-in-noise and in

noise only conditions, and (2) a study to evaluate comfort and loudness ratings.

Study 1: Listener Preferences

Sixteen hearing aid users with symmetric mild to moderately severe sensorineural hearing loss were recruited for this study (*Figure 1*). Participants ranged in age from 57 to 88 years ($M = 74$, $SD = 8.6$). Seven participants were female. All participants had prior experience wearing hearing aids and were familiar with their use in daily listening environments.

Hearing Aid Fitting

Participants were fitted with RIC RT and mRIC R rechargeable hearing aids using coupling configurations appropriate for their hearing loss and ear anatomy. Three participants used open fittings, while thirteen participants used occluded fittings. Among the occluded fittings, eight utilized occluded earbuds, one used power domes, and four were fitted with custom earmolds. 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 week. After the trial period, a laboratory-based preference test was conducted.

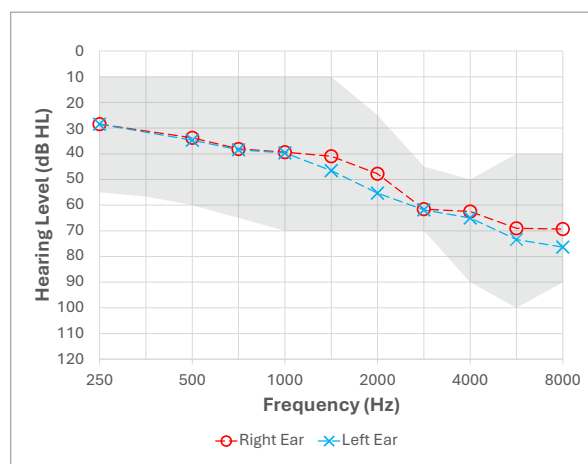


Figure 1: Average audiogram for 16 participants in Study 1. Red (circles) and blue (crosses) dashed lines and symbols show the average hearing levels for the right and left ears respectively, with the range denoted by the shaded gray area.

Recordings for the Preference Test

To assess listener preference, a paired comparison test, considered one of the most sensitive methods (Amlani & Schafer, 2009), was used. Since activation of Edge Mode settings requires an adaptation period, conducting an in-situ paired comparison was not feasible. Instead, each participant's fitting and coupling configuration was used to create recordings using a KEMAR manikin with the Legacy Edge Mode Reduce Noise and the Improved Edge Mode Reduce Noise. All recorded stimuli were then calibrated and presented to participants via a pair of Sennheiser HD-600 headphones.

Four acoustic scenarios were used in the study:

1. Male talker in a busy restaurant (diffuse noise),
2. Female talker in a food court (Ambisonic recording from the Ambisonics Recordings of Typical Environments (ARTE) database) (Weisser et al., 2019),
3. Male talker in Café 07 (Ambisonic recording from the ARTE database), and
4. Noise-only condition in a busy restaurant (diffuse noise).

For scenarios (1) – (3), participants were asked to indicate their overall preference. For (4), participants were asked to indicate which recording has the least amount of noise. For the three speech-in-noise scenarios, the signal-to-noise ratio (SNR) was set at +3 dB. These scenarios were selected to provide high ecological validity and realism, as they represent common, challenging listening environments encountered by hearing aid users in everyday life (Wu et al., 2019). The participants compared each pair of recordings (Legacy and Improved Edge Mode Reduce Noise) and indicated whether they preferred one recording, the other recording, or had no preference. For the noise-only condition, the participant was asked to compare each pair of recordings and

indicate which recording had the least amount of noise. Each stimulus was repeated three times. For each stimulus, the winning model (majority vote) was defined as the model (legacy or DNN) that was selected in at least two of the three presentations.

Results

Preference ratings were analyzed using a linear mixed effects model, with acoustic scenario included as a fixed effect and participant modeled as a random intercept. For each algorithm pair, a total of 144 ratings were collected across the three speech in noise scenarios (16 participants × 3 scenarios × 3 repetitions), and 48 ratings were collected for the noise only condition (16 participants × 1 scenario × 3 repetitions).

Results showed a significant overall preference for the Improved Edge Mode Reduce Noise over the legacy version when preference data from all three speech in noise scenarios were combined ($p = 0.002$; see Figure 2). In addition, during noise only listening conditions, the Improved Edge Mode Reduce Noise setting was rated as having significantly lower perceived noise than the legacy setting ($p < 0.001$; see Figure 3 on the next page).

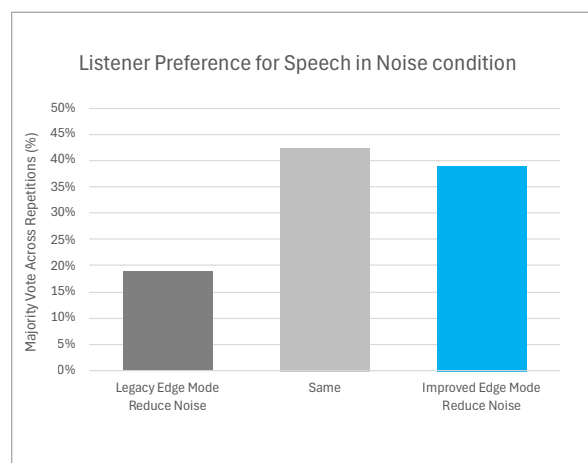


Figure 2: Paired-comparison for the headphone study comparing the listening preferences of the Legacy and Improved Edge Mode Reduce Noise settings in speech-in-noise conditions. The bar chart shows the number of ratings assigned to each response category (Legacy Edge Mode Reduce Noise, Improved Edge Mode Reduce Noise, and Same).

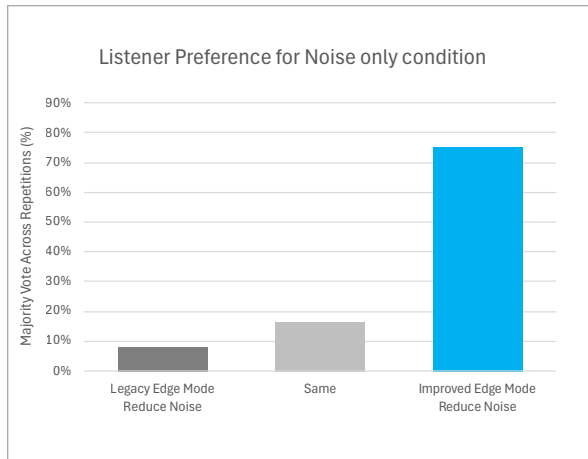


Figure 3: Paired-comparison results evaluating listener ratings for recordings with the least perceived background noise in noise-only conditions for the legacy and enhanced DNN models. The bar chart shows the number of ratings assigned to each response category (Legacy DNN Model, Enhanced DNN Model, Same).

Study 2: Loudness and Comfort ratings

Thirty-nine hearing aid users with symmetric sensorineural hearing loss were recruited for this study (Figure 4). Eligibility required a comprehensive hearing evaluation within the preceding 12 months, which included assessment of speech-in-noise performance using the QuickSIN. Participants ranged in age from 28 to 86 years ($M = 69$, $SD = 12.4$). Sixteen participants were female. All participants had prior experience wearing hearing aids and were familiar with their use in daily listening environments.

Hearing Aid Fitting

Participants were fitted with Starkey Omega AI+ 24 RIC RT, mRIC R, ITE R, ITC R, and CIC hearing aids using coupling configurations and venting appropriate for their hearing loss and ear anatomy. For the RIC participants, six used earmolds, four used open earbuds, three used occluded earbuds, and two used power earbuds. 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 approximately one month.

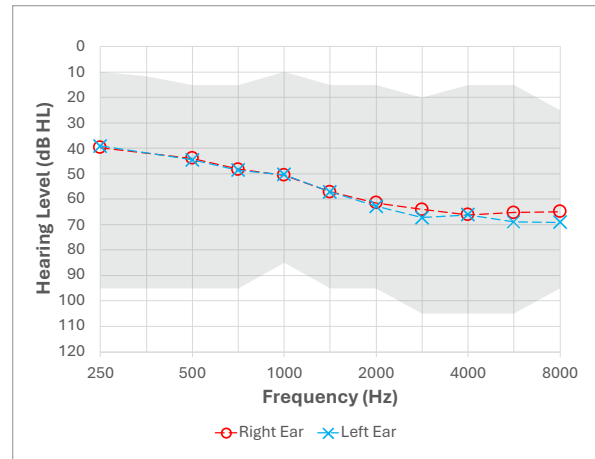


Figure 4: Average audiogram for 39 participants in Study 2. Red (circles) and blue (crosses) dashed lines and symbols show the average hearing levels for the right and left ears respectively, with the range denoted by the shaded gray area.

Methods

Participants were counseled on the Automatic Edge Mode feature at the fitting session and instructed to assess the feature during the first field trial. At the two-week follow-up session, participants were introduced to the new Always-on Edge Mode feature and given the option to continue using it throughout the remainder of the study.

After approximately one month in the field, participants completed two lab assessments: a loudness and a listening comfort rating task. The perceived loudness and listening comfort tasks were designed to evaluate subjective outcomes across four different listening conditions: Personal, Edge Mode Best Sound, Edge Mode Enhance Speech, and Edge Mode Reduce Noise, with the enhanced DNN algorithm in the Reduce Noise condition. Stimuli were presented in a controlled sound-field environment with diffuse noise presented simultaneously from an eight-speaker array (72 dB C, summed level; 45° azimuth spacing). Following each condition, participants rated perceived loudness (1= very soft, 7= uncomfortably loud) and listening comfort (1= extremely comfortable, 7= extremely uncomfortable).

Results

Loudness and comfort ratings were evaluated using linear mixed-effects models, with the pattern of significant effects varying across Edge Mode programs and listening environments. These findings generally aligned with the intended design goals of the Edge Mode settings providing targeted benefits based on listening needs.

For the subjective loudness ratings (*Figure 5*), a linear mixed-effects model revealed a significant effect of hearing aid condition on the perceived loudness of noise. Relative to the Personal condition, Edge Mode Reduce Noise was associated with significantly better loudness perception ($B = -0.62$, $p < 0.001$), whereas Edge Mode Best Sound and Edge Mode Enhance Speech did not differ significantly from Personal ($p = 0.09$ and $p = 0.64$, respectively). Post hoc pairwise comparisons indicated that Edge Mode Reduce Noise (mean = 4.59) produced significantly lower loudness ratings compared to Personal memory (mean = 5.22; $p = 0.003$, Bonferroni-corrected), demonstrating improved loudness perception in diffuse noise. This finding aligned with expectations for Reduce Noise, which was designed to decrease the prominence of background sounds and prioritize listening comfort in complex listening situations.

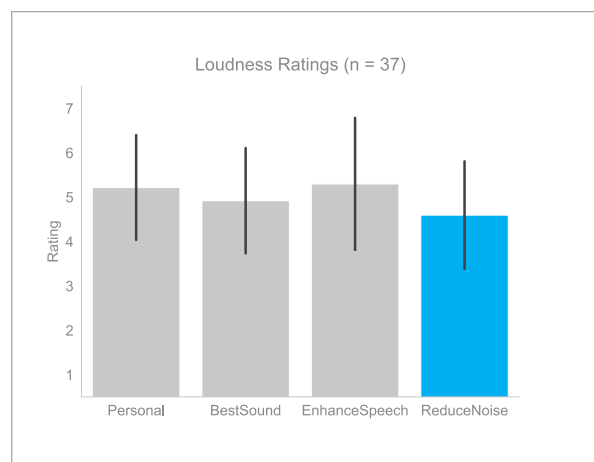


Figure 5: Subjective loudness rating results for the listening comfort lab assessment. Lower values indicate less perceived loudness [1: very soft, 7: uncomfortably loud]. Error bars represent ± 1 SD.

For the subjective comfort ratings (*Figure 6*), a linear mixed-effects model revealed a significant effect of condition on comfort ratings. Relative to the Personal condition, Edge Mode Best Sound and Edge Mode Reduce Noise were associated with significantly better comfort ($B = -0.40$, $p = 0.03$ and $B = -0.65$, $p < 0.001$, respectively), whereas Edge Mode Enhance Speech did not differ significantly from Personal ($p = 0.47$). Post-hoc analysis revealed that the Edge Mode Reduce Noise condition (mean = 3.89) resulted in significantly lower discomfort ratings compared to Personal memory ($B = -0.65$, $p = 0.003$, Bonferroni-corrected), indicating improved perceived comfort in diffuse noise. This result further supports the intended role of Reduce Noise as a comfort-focused listening option for demanding acoustic environments.

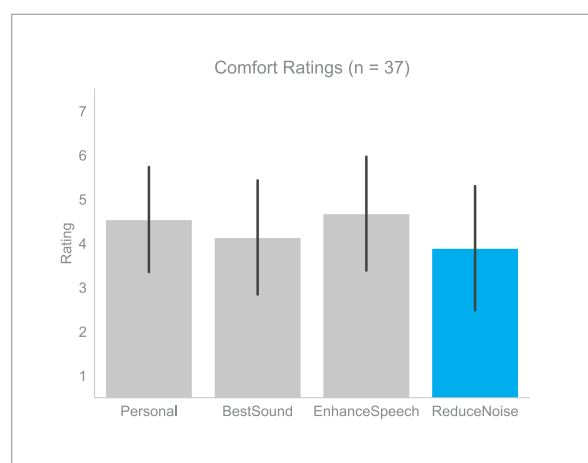


Figure 6: Subjective comfort rating results for the listening comfort lab assessment. Lower values indicate greater perceived comfort [1: extremely comfortable, 7: extremely uncomfortable]. Error bars represent ± 1 SD.

Edge Mode Enhance Speech Evaluation

Edge Mode Enhance Speech was evaluated to study the impact of the feature in relation to default Personal setting as well as the Best Sound available in the Edge Mode feature. Previous studies (*Rakita and Harianawala (2021)*, *Jaekel and Xu (2024a, 2024b)*) demonstrated effectiveness in improved speech understanding and noted

correlates with perceived task demand and demographic metrics. In this study, individual responses varied and exploratory analyses were conducted to examine relationships between benefit and listener characteristics, including age, preference for the Always-on Edge Mode feature, and speech-in-noise ability.

Methods

Participants from Study 2 were assessed with a speech task consisting of Institute of Electrical and Electronics Engineers (IEEE) sentences (*Campbell & Reynolds, 1999*) presented in multi-talker babble noise, with 20 sentences per condition. Performance was quantified as percent correct based on keyword identification. Speech stimuli were presented from a loudspeaker at 0° azimuth at individualized signal-to-noise ratios (SNRs) corresponding to each participant's SRT70, measured using the Personal program. The multi-talker babble noise was presented simultaneously from an eight-speaker array (65 dB C, summed level; 45° azimuth spacing). Following each condition, participants rated perceived listening effort (1 = no effort, 7 = extreme effort). Based on previous assessments of Edge Mode Enhance Speech, a positive outcome in listening effort was anticipated.

Listening Effort Outcomes

For the subjective listening effort ratings (*Figure 7*), a linear mixed-effects model revealed a significant effect of condition on listening effort ratings. Relative to the Personal condition, Edge Mode Enhance Speech was associated with significantly lower listening effort ($\beta = -0.40$, $p = 0.005$), whereas Edge Mode Reduce Noise resulted in significantly higher effort ($\beta = 0.42$, $p = 0.003$). Edge Mode Best Sound did not differ significantly from Personal ($p = 0.93$). Post hoc pairwise comparisons indicated that Edge Mode Enhance Speech (mean = 5.21) produced significantly lower listening effort ratings compared to Personal

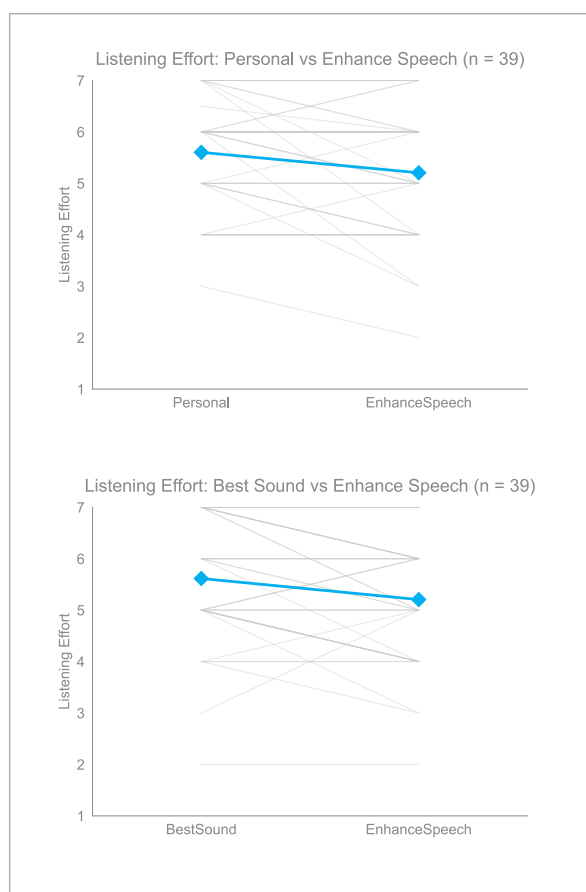


Figure 7: Subjective listening effort rating results. Lower values indicate less perceived listening effort (1: no effort, 7: extreme effort). Blue diamonds indicate mean listening effort ratings.

condition (mean = 5.60; $p = 0.020$, Bonferroni-corrected) and compared to Best Sound condition (mean = 5.62; $p = 0.010$, Bonferroni-corrected), demonstrating improved listening effort in multi-talker babble noise. This outcome was consistent with the intended purpose of Enhance Speech, which was designed to prioritize speech signals.

While the group-level comparisons aligned with expectations, variability in individual responses highlights the challenge of predicting which patients will benefit from noise reduction strategies, therefore, exploratory analyses were conducted to identify listening characteristics associated with Edge Mode benefit.

The Edge Mode benefit was calculated as the difference in speech performance between the

Edge Mode condition (Best Sound or Enhance Speech) and the Personal condition, expressed in percentage points, with positive values indicating greater benefit from the Edge Mode condition.

Always-on Edge Mode Preference and Benefit

To evaluate whether Edge Mode benefit differed as a function of Edge Mode preference, participants were separated into two groups based on status of the Always-on Edge Mode feature at the final session. After an average of 45 days in the field, approximately half of the participants still had the Always-on Edge Mode feature enabled by preference.

The group with Always-on Edge Mode enabled at the final session showed greater Edge Mode benefit in Best Sound and in Enhance Speech compared to participants with Always-on Edge Mode disabled at the final session (Figure 8). While not statistically significant, the observed pattern suggests that users who prefer Edge Mode, or who use the feature more frequently, may be more likely to benefit from Best Sound or Enhance Speech.

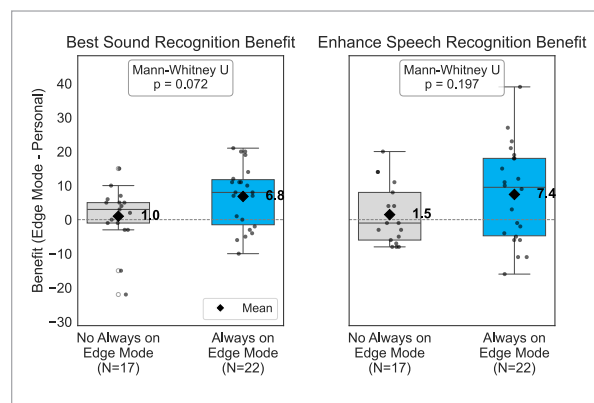


Figure 8: Edge Mode benefit for Study 2 participants separated by status of Always on Edge Mode feature at the final session.

Age and Edge Mode Benefit

To explore factors associated with individual differences in Edge Mode benefit, an exploratory analysis was conducted examining the

relationship between age and Edge Mode benefit. As shown in Figure 9, a Spearman correlation analysis revealed a positive, but non-significant, association with age ($p = 0.28$, $n = 39$, $p = 0.089$), suggesting a potential tendency for greater benefit from Edge Mode Enhance Speech among older participants. Neither age and PTA nor PTA and Edge Mode benefit were significantly correlated ($p = 0.00$, $p = 0.978$; $p = 0.09$, $p = 0.572$, respectively). Together, these findings suggest that the observed age-related trend was not attributable to differences in hearing loss severity.

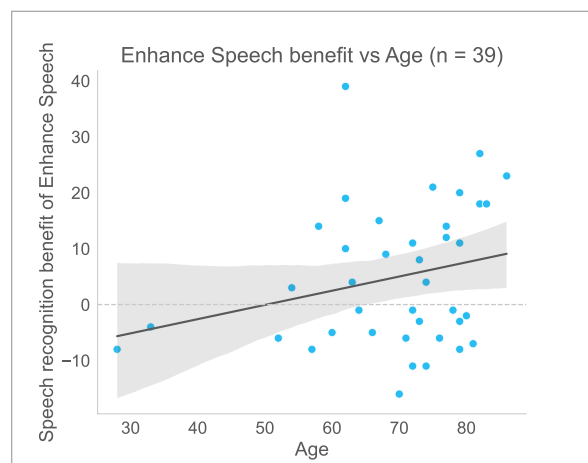


Figure 9: Relationship between age and speech recognition benefit of the Edge Mode Enhance Speech, calculated as the difference in recognition performance between Edge Mode Enhance Speech and the Personal program.

Speech-in-Noise Ability and Edge Mode Benefit

To evaluate whether Edge Mode benefit differed as a function of speech-in-noise ability, participants were grouped based on their unaided QuickSIN (Killion et al., 2004) performance. Listeners with poorer speech-in-noise performance (QuickSIN SNR Loss > 7 dB) demonstrated greater Enhance Speech benefit than listeners with better speech-in-noise performance (QuickSIN SNR Loss ≤ 7 dB). This trend was evident when all participants were included (RIC RT, mRIC R, ITE R, ITC R, and CIC), with the poorer QuickSIN

group demonstrating a mean benefit of 10.5 percentage points compared to 2.2 percentage points for the better QuickSIN group. Although the difference did not reach statistical significance (Mann-Whitney U test, $p = 0.068$), the observed magnitude of benefit in the poorer QuickSIN group is considered clinically meaningful (Stipancic et al., 2025).

Directional microphone technology is well established as a means of improving speech understanding in noise (Hornsby & Ricketts, 2007). To determine whether directional processing contributed to the observed relationship between baseline speech-in-noise ability and Enhance Speech benefit, a follow-up analysis was conducted using only participants fit with directional devices (RIC RT, mRIC R, ITE R, and ITC R). Within this subgroup, listeners with poorer speech-in-noise ability demonstrated significantly greater Enhance Speech benefit than listeners with better speech-in-noise ability (Mann-Whitney U test, $p = 0.036$), with mean benefits of 11.7 and 0.8 percentage points, respectively (Figure 10). These findings suggest that listeners who experience greater difficulty understanding speech in noise may derive the greatest benefit from the Enhance Speech setting, particularly when directional microphone technology is utilized.

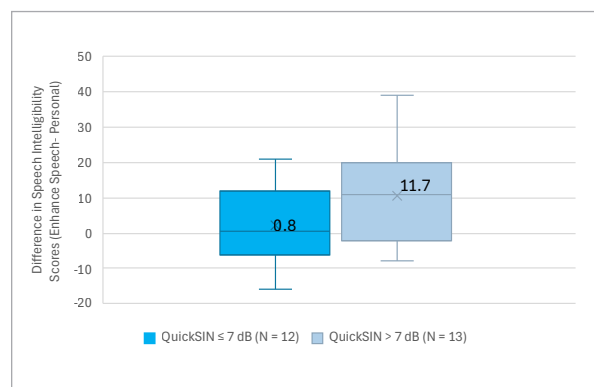


Figure 10: Differences in Enhance Speech and Personal recognition benefit for directional participants (RIC RT, mRIC R, ITE R, ITC R) grouped by unaided QuickSIN performance

Conclusion

The next generation Edge Mode with DNN enhanced Reduce Noise demonstrates measurable and meaningful improvements in listener preferred outcomes compared to the previous Reduce Noise implementation.

Across three realistic speech-in-noise environments, listeners showed a significant overall preference for the enhanced DNN algorithm relative to the legacy DNN algorithm (Study 1). In addition, the enhanced DNN algorithm was consistently rated as having lower perceived noise, reflecting improvements in listening comfort. Together, these results indicate that the enhanced DNN algorithm more effectively balances noise suppression and sound quality in highly challenging listening situations.

These findings are further translated into perceptible benefits as evidenced in Study 2. Significant benefits were found in lower listening efforts for Enhance Speech and in increased listening comfort and reduced loudness for Reduce Noise.

Additionally, participants with poorer unaided QuickSIN performance experienced greater speech-recognition benefit from Enhance Speech, with statistically significant effects observed among users fit with directional microphone technology. Findings also suggest that individual listener characteristics and feature-use patterns may influence the magnitude of benefit. While not statistically significant, a trend was observed between Always-On Edge Mode usage and measured benefit, indicating a potential relationship that may warrant further investigation.

By combining enhanced deep neural network processing with user driven control, the next generation Edge Mode continues to support Starkey's approach of prioritizing individual

listening intent and preference. While Best Sound remains the recommended default Edge Mode setting, providing an optimal balance of speech understanding, listening comfort, and overall sound quality across a wide range of environments, the findings in these studies demonstrate that alternative Edge Mode options can provide meaningful additional benefit when specific listening challenges or goals arise. These findings further reinforce Edge Mode as a powerful solution for complex real world environments, delivering enhanced listening comfort and preferred sound quality for hearing aid users.

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Author Biographies



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.



Jiayue Liu, Ph.D. is a Research Scientist at Starkey Hearing Technologies in Eden Prairie, Minnesota. Her work focuses on evaluating hearing aid features and user preferences in laboratory and real-world environments, including study design, behavioral research, data analysis, and hearing technology assessment. She joined Starkey in January 2025 after completing her Ph.D. at Duke University, where her research focused on hearing loss, speech perception, auditory neuroscience, and EEG-based measures of listening difficulties.



Jingjing Xu, Ph.D., is a research scientist in the department of clinical and audiology research at Starkey. Before joining Starkey in 2016, he was a research assistant professor of audiology at the University of Memphis. He received his master's degree in engineering acoustics from the Technical University of Denmark and his Ph.D. in Communication Sciences and Disorders from the University of Memphis. His research interests include acoustics, speech recognition, hearing aid outcome measures, and ecological momentary assessment.



Daniel Marquardt received his Dipl.-Ing. degree in media technology from the Ilmenau University of Technology, Ilmenau, Germany, and his Dr.-Ing. degree in speech signal processing from the University of Oldenburg, Oldenburg, Germany, in 2010 and 2015 respectively. From 2015 to 2017, he was a Postdoctoral Researcher with the University of Oldenburg, Germany. He currently works as a Principal Signal Processing Engineer at Starkey.