

Optimizing Hearing Aid Sound Quality Through Deep Learning Control of Compression



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Key takeaways:

- Starkey's new DNN-based compression system achieves an excellent balance between improving hearing performance and minimizing distorted sound quality.
- The DNN Dual Compressor is preferred to the Legacy Compressor system both in the laboratory and in the field, and was shown to achieve a better balance of audibility, sound quality, and speech recognition.

Introduction

Dynamic range compression is the fundamental signal processing operation performed by modern hearing aids. It restores audibility of soft sounds while ensuring that louder sounds remain comfortable (see [The Compression Handbook \[2026\]](#) for a detailed overview of the underlying concepts). Many considerations govern the design of compression systems. Parameters such as knee points, compression ratios, attack and release times, and the choice of single- or multiple-channel designs significantly influence performance and patient benefit. A well-designed system achieves the optimal balance in patient outcomes for loudness, speech reception, and natural sound quality.

Starkey utilizes a dual compression architecture in which fast and slow systems operate in parallel before combining. The slow compressor is guided by the audiogram and ensures that sounds on average are within the patient's dynamic range of hearing.

This means that soft sounds are audible, average sounds are comfortable, and loud sounds are not excessively loud. By operating on a slow time scale, this processing is less likely to introduce signal distortions that degrade sound quality and spatial impression even if it may fail to achieve adequate loudness of brief transient sounds.

In contrast, the fast compressor controls the loudness of brief transient sounds by acting on rapid fluctuations in the audio signal. Its primary role is to enhance audibility of soft transient signal elements such as consonants, while reducing the amplitude contrast between louder and quieter segments of the audio. This results in more gain for soft sounds without compromising overall listening comfort. Past research has shown that fast compression strategies improve intelligibility of soft speech when SNR is high, and when speech occurs in fluctuating noise backgrounds (*Verschuure et al 1998; Souza and Sirow, 2014; Kowalewski et al, 2018; Kowalewski et al, 2020*).

Rapid gain changes inherent to fast-acting compression can produce unpleasant signal distortions and artifacts (e.g., *Chen et al., 2021*). One such artifact can be noticeable in certain situations where no speech is present. Because fast time constants also reduce gain for sounds occurring immediately after a louder signal, brief portions of softer sounds will be attenuated. In environments containing a low-level background noise and repetitive transient sounds such as keyboard typing, metronome clicking, or clock ticking, the result is momentary reduction of the background noise adjacent to each transient. (*Figure 1*). The resulting rapid fluctuation of the background noise produces a “pumping” sensation, which listeners may find distracting or unpleasant.

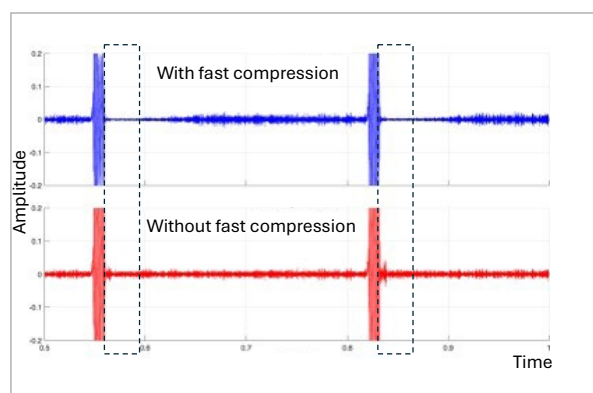


Figure 1: An example of gain reduction due to fast compression in a metronome signal. The top panel shows portion of the signal that is reduced due to fast compression while the bottom panel shows the unprocessed signal. The dashed boxes highlight the differences in gain between the processed and unprocessed signals.

An optimal compressor design achieves appropriate loudness, comfort, and speech intelligibility for all sounds without causing unpleasant distortions like pumping that degrade sound quality.

With Omega AI+, Starkey introduces a Deep Neural Network (DNN) – based control mechanism that uses the presence of speech in the signal to dynamically regulate the dual-path compressor. By intelligently controlling the contribution of fast and slow compression, the

DNN dual compressor helps strike an optimal balance of improved audibility for soft speech transients and preserves natural sound quality.

As discussed above, fast-acting compression has been shown to be effective in improving intelligibility but can introduce “pumping” sensations. A targeted inactivation of fast compression during non-speech segments can minimize the possibility that pumping events become a significant factor in the sound quality. We determined that our DNN is 92% accurate at identifying speech from non-speech, when evaluated on a large audio dataset comprising unique speakers and an equal number of speech and non-speech conditions (taken from the Deep Noise Suppression Challenge #3 (*Reddy et al., 2021*)). Non-speech presentations were correctly identified with the probability of 94%. This means that a large fraction of the pumping events that might have arisen from fast compression do not manifest in the hearing-aid response, thereby improving sound quality significantly.

We report results of a study comprising lab and field components that evaluated the hypothesis that users are less likely to encounter pumping artifacts with the new DNN-controlled Dual Compressor compared to the Legacy Compressor.

Clinical data

The DNN Dual Compressor is designed to prioritize sound quality by reducing the probability of noticeable artifacts. To evaluate this hypothesis of fewer experienced pumping artifacts, a clinical study was carried out involving fourteen experienced bilateral hearing aid users with mild to moderately severe hearing loss (age range: 49–89 years, mean = 73.8, SD = 9.3; 9 males, mean audiogram shown in Figure 2).

Participants were fitted with Starkey’s Omega AI+ RIC RT and mRIC R hearing aids using clinically appropriate couplings.

Each hearing aid was programmed with two programs: one with the DNN Dual Compressor and one with the Legacy Compressor.

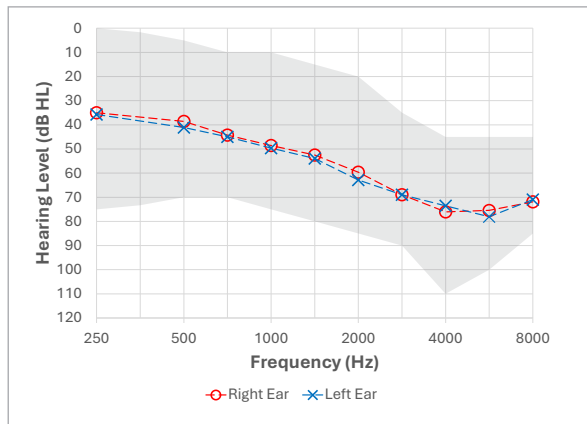


Figure 2: Mean right (red circles, dashed line) and left (blue cross, dashed line) audiogram with the shaded region representing the range of the participants' hearing thresholds (N=14).

Lab evaluation

In a controlled laboratory setting, study participants performed a sound-field paired comparison test using 13 stimuli such as clock ticking, dog barking, keyboard clicking, and a metronome. All stimuli were presented at 55 dB SPL from a single loudspeaker positioned at 0° azimuth. The study included two tasks: (1) participants listened to each stimulus in both programs and indicated their preference; (2) participants evaluated each stimulus in both programs and reported which contained artifacts after previously being trained to identify them by listening to samples with and without artifacts. Table 1 shows the rating scales in the two tasks.

The results of Task 1 are shown in Figure 3. At the group level, participants exhibited a significant preference for the sound quality of the DNN Dual Compressor compared with the Legacy Compressor, as indicated by a linear mixed-effects model, $t(13) = 2.95$, $p = 0.01$.

At the individual level, 9 out of 14 users (64%) expressed an explicit preference for the DNN

Table 1: Question and response scales used in the lab-based preference test.

	Task 1	Task 2
Question	Switch between button "A" and "B" and compare the two sound processing conditions, select preference based on sound quality	Switch between button "A" and "B" and compare the two sound processing conditions, select the condition with pumping
Rating scale	• A Preferred • A Slightly Preferred • No Preference • B Slightly Preferred • B Preferred	• Condition A • Condition B

Dual Compressor compared to the Legacy Compressor and 13 out of the 14 (93%) of listeners had no preference or preferred the sound quality of the DNN Dual Compressor compared to the Legacy Compressor.

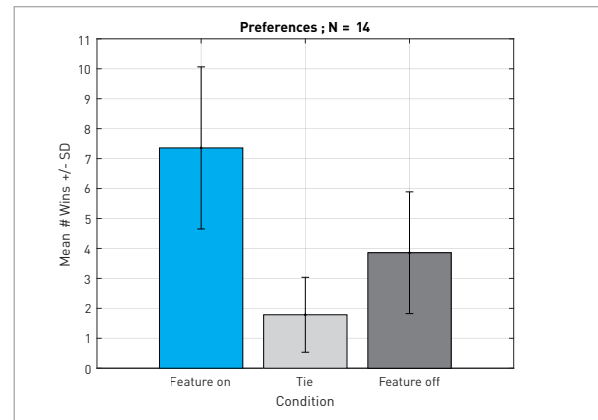


Figure 3: Significant preference for the sound quality of the DNN Dual Compressor over the legacy system. A "win" means that either the DNN Dual Compressor or the Legacy Compressor was selected on at least two out of the three times that a stimulus was evaluated.

The results of Task 2, where participants were asked to choose which condition had a pumping artifact, showed a reduction in perceived artifact with the DNN Dual Compressor (Figure 4 on next page). At a group level, the program with the DNN Dual Compressor was deemed to be almost four times less likely to contain artifacts than the program with the Legacy Compressor.

This difference was statistically significant, as indicated by a linear mixed-effects model ($t(6.4) = -9.79$, $p < 0.001$). At the individual level, all 14 users (100%) rated the DNN Dual Compressor as having fewer artifacts than the Legacy Compressor.

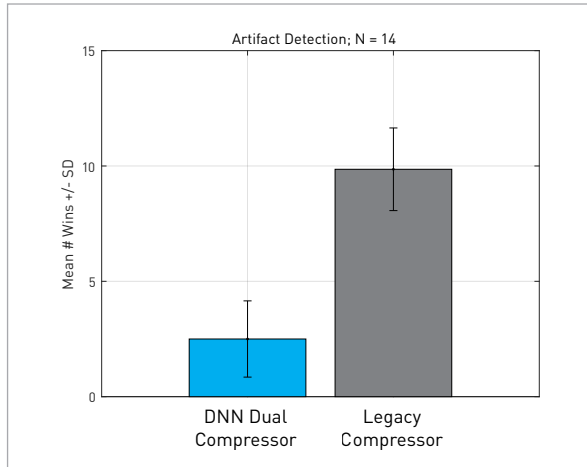


Figure 4: Significantly fewer artifacts detected with feature enabled versus feature disabled. A “win” was determined in the same manner as in Figure 3.

To confirm that these benefits for sound quality were not coming at a cost to speech recognition, the reception of soft speech (55 dB SPL) in both quiet and low-level background noise (50 dB SPL) were evaluated using the American Four Alternative Auditory Feature test (Foster & Haggard, 1987; Xu & Cox, 2014).

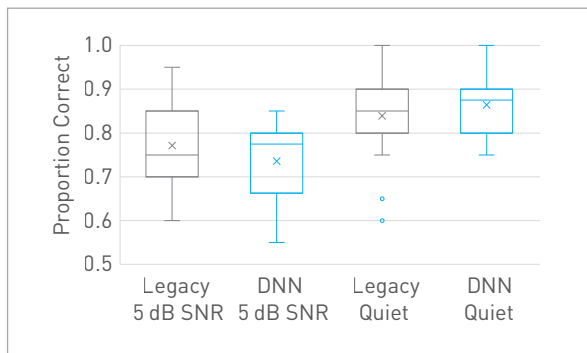


Figure 5: Boxplot of speech recognition at 55 dB SPL using the American Four Alternative Auditory Feature test, evaluated at 5 dB SNR and in Quiet, comparing conditions for when the DNN Dual Compressor (“DNN”) and the Legacy Compressor (“Legacy”) are used. Boxes represent the interquartile range with the median indicated by the horizontal line and the mean marked by an “x”.

Figure 5 showed that there was no statistically significant impact on speech recognition of enabling the DNN Dual Compressor (Wilcoxon, $p = 0.27$ for the 5 dB SNR condition, and Wilcoxon, $p = 0.11$ for the Quiet condition).

Field evaluation

The distinctions between the DNN Dual Compressor and the Legacy Compressor were expected to be less evident in a field study because of the limited experimental control over the conditions for comparing the two programs. For example, it is nearly impossible to ensure that the acoustic environment is the same during the assessment of each program.

Nevertheless, study participants were asked to describe their listening environments and indicate preference between the programs in each of these environments. For this purpose, participants were given a custom mobile application that allowed switching between programs and selecting a judgment from a brief menu of choices. Through a combination of instruction and time- and level-based triggering of the app-based survey, preference judgments were obtained in both targeted environments (e.g., “pen click in bathroom with exhaust fan running”) and environments where no effect would have been expected (e.g., “TV in other room”).

The study hypothesized that 1) the DNN Dual Compressor-enabled program would be preferred in the targeted environments and 2) this preference would be less strong, if at all, in the untargeted environments.

Twelve of the 14 participants successfully completed the app-based surveys, resulting in 169 survey responses in total. When the survey data about preference were examined at the individual participant level, 11 of the 12 participants (92%)

rated the DNN Dual Compressor as equal to or better than the Legacy Compressor. The preference data from the field pooled across all participants is shown in Figure 6. In untargeted environments (Figure 6A), participants selected the two settings at roughly equal rates. In contrast, in targeted environments (Figure 6B), the DNN Dual Compressor ON condition was chosen twice as often as the feature OFF condition. However, many ‘No preference’ responses were still observed, likely because artifacts were either not noticeable or not present.

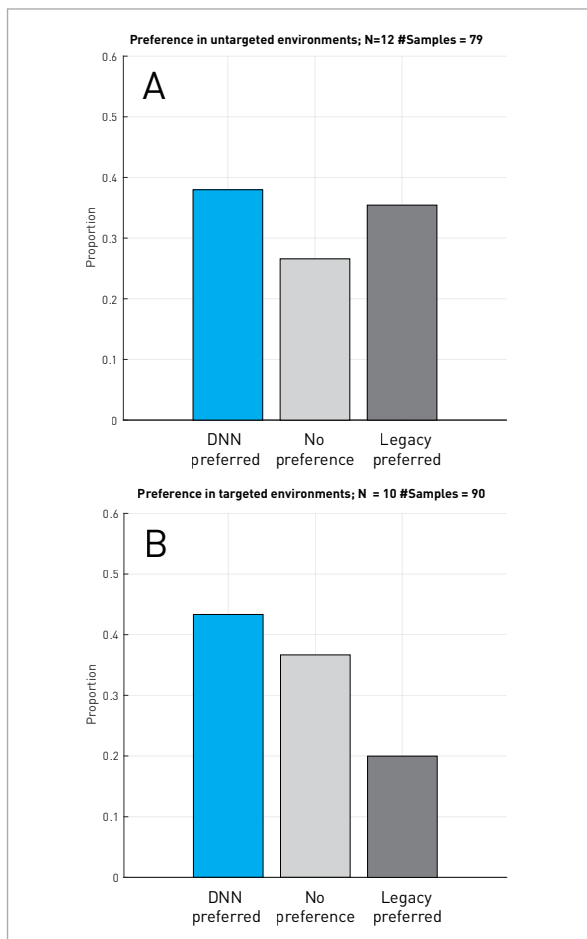


Figure 6: the App-based preference evaluation in the field comparing the DNN Dual Compressor (“DNN”) and the Legacy Compressor (“Legacy”) when the participant was in (A) untargeted and (B) targeted environments.

Given the unbalanced data across participants and the three outcome categories (DNN Dual Compressor preferred, No preference, and Legacy Compressor preferred), a Bayesian multinomial logistic mixed effects model (Bürkner, 2017) was used to estimate group differences between the DNN Dual Compressor and the Legacy Compressor while accounting for listener variability.

The probabilities of preference estimated in the model were analyzed with respect to the two aforementioned hypotheses.

With respect to the first hypothesis, the posterior probability of the DNN Dual Compressor over the legacy compressor in targeted environments was 0.86. In Bayesian terms, this is moderate evidence bordering on strong evidence that the DNN Dual Compressor is preferred by users when in targeted environments.

With respect to the second hypothesis, our model estimated a posterior probability of 0.73 that a preference for DNN Dual Compression is less in untargeted environments than in targeted environments. In Bayesian terms, this is moderate evidence bordering on weak evidence that users could more readily distinguish the DNN Dual Compressor from the legacy processing in targeted environments than in untargeted environments. This weak distinction of the processing effects between targeted and untargeted environments is not unexpected because of our reliance on descriptions generated by people inexperienced at accurately describing sounds to decide if an environment was targeted or untargeted.

Overall, we can conclude that there is moderate evidence in the field trial for the DNN Dual Compressor being a more appealing option in conditions where artifacts are present and noticeable.

Conclusion

Starkey's DNN Dual Compressor represents a significant advancement in hearing aid compression technology by reducing compression-related artifacts while improving overall sound quality compared to the Legacy Compressor system. Clinical findings demonstrated a clear user preference for the DNN Dual Compressor in both laboratory and real-world environments, with listeners consistently reporting fewer pumping artifacts and a more pleasing listening experience. Importantly, these sound quality improvements were achieved without compromising speech recognition performance. Field study results further showed that users were more likely to prefer the DNN Dual Compressor in situations where pumping artifacts were most noticeable.

Together, these findings suggest that the DNN Dual Compressor provides a more effective balance of audibility, sound quality, and speech understanding, helping deliver a more natural and satisfying listening experience for hearing aid users.

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Author Biographies



Kenneth K. Jensen, Ph.D., received his doctorate in neurobiology from the University of Southern Denmark, Denmark. He has published wide-ranging research in auditory perception and vocal communication in both animals and humans, involving psychoacoustics, acoustic measurements, modeling, x-ray cinematography, and many other techniques. He has worked with hearing aids and cochlear implants over the last decade including key topics like noise reduction, environmental classification, compression, hearing aid fitting software and strategies. He is currently a Principal Signal Processing Engineer with the Algorithms and Data Technology team at Starkey.



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Henning Schepker received his MSc degree (with distinction) in Hearing Technology and Audiology in 2012 and his PhD degree in signal processing for hearing aids in 2017 both from University of Oldenburg, Germany. Before joining Starkey in Spring 2020, he worked as a post-doctoral researcher on signal processing for hearing aids at the University of Oldenburg. He is currently a Manager of Algorithm Development at Starkey and is passionate about improving the next generation of hearing aids and applying his expertise in feedback reduction, dynamic range compression and ear canal acoustics.



Ben Waite, M.Eng, is a Principal Firmware Engineer at Starkey who specializes in compression and noise reduction algorithms. Ben joined Starkey in 2014 and has held several roles within the Research and Development department, spanning Feature Management, Systems Engineering and Firmware Development teams. Since joining the team, Ben has made significant contributions to the design and implementation of various hearing aid features, as well as the development of simulation tools that are used to better understand and evaluate hearing aid algorithms.