Pro Fit Acoustic Model Optimization: A Better, Faster Fit

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Executive summary

- With Genesis AI, Starkey Pro Fit fitting software features a functionality called acoustic model optimization (AMO)
- AMO runs alongside feedback-canceller (FBC) initialization and uses in-situ measurements to estimate acoustic-coupling characteristics with the hearing aid or receiver in place in the ear.
- AMO notifies the hearing care professional when acoustic-model parameters must be updated to more accurately match the in-situ acoustics while taking into account the selected acoustic-coupling option.
- AMO offers hearing care professionals faster and more accurate hearing aid fittings because of more accurate, individualized predictions of real-ear responses and gains by the fitting software and more accurate real-ear target matching. It can also improve the accuracy of hearing-threshold measurements through the hearing aid using the in-situ Audiometer in Pro Fit.
- AMO may benefit patients with improved audibility, speech intelligibility, and better sound quality as a result of more accurate vent-effect corrections.

Introduction

A desirable goal for hearing care professionals and their patients is to obtain an optimized, custom fit with as little time and effort as possible.

While prescription formulas provide a convenient starting point for hearing-aid gain settings, their practical usefulness hinges on how well gains in the ear match the targets. Prior to collecting real-ear measures, professionals must rely on acoustic-model predictions (predicted real-ear responses and gains) computed by the fitting software.

By default, these predictions are based on average (non-individualized) parameters. Although these parameters are age- and gender-specific, they may not reflect accurately the in-situ acoustics of the individual ear being fitted. For example, an occluded or power dome can yield a well-occluding fit in some ears, and a much more open fit in others *[Figure 1]. (See also Caporali et al., 2019.)*

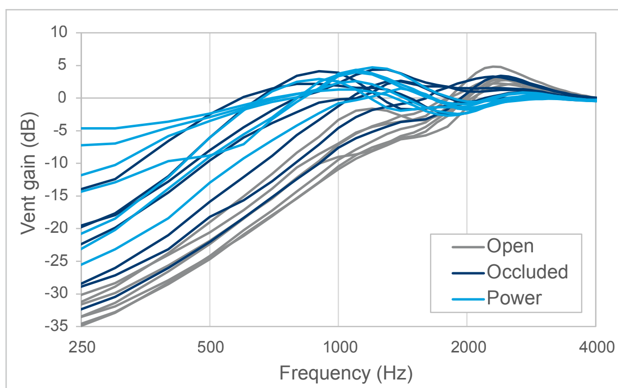

Figure 1. Measured outward sound leakage for three dome types, in different ears.

Even if the acoustic fit is subsequently verified using real-ear measurements with a probe tube, and gains are adjusted accordingly, accurate initial settings can speed up the fitting and verification process by reducing the number or magnitude of needed gain adjustments.

Therefore, whether real-ear measures are performed or not, the fitting process is likely to be accelerated if the acoustic model used inside the hearing aid fitting software is more accurate.

Improving acoustic-model predictions without a probe tube

Obtaining real-ear measures using a hearing aid, without using a probe tube, involves playing a sound through the receiver and measuring how much sound is fed back to the device microphone. Provided that the receiver and microphone are both functioning normally and that the test environment is reasonably quiet, how much sound is fed back to the microphone is directly related to how much sound leaks out through any vent(s) and/or slit leaks around the bud, mold, or shell. The bigger the vent or slit leaks, the more sounds leak out of the ear canal, and the higher the sound pressure level picked up by the microphone. Thus, acoustic feedback measurements can be used to estimate vent leakage.

In-situ measurements of acoustic feedback are obtained as part of feedback canceller initialization, which is normally performed at the beginning of a hearing aid first fitting. These measurements can also be used to determine sound-leakage effects for the current acoustic coupling. This is where the Starkey acoustic model optimization feature in the Pro Fit fitting software comes in.

How does AMO work? What does it do?

The AMO feature leverages in-situ acoustic measurements to estimate characteristics of the acoustic coupling between the device and the ear — in particular, how much sound leaks out of the ear canal. The algorithm then combines this information with other data, including but not limited to the currently selected acoustic option, to determine whether different acoustic-model parameters than those currently used for the considered fitting are more adequate. It also determines whether acoustic-model parameters need updating.

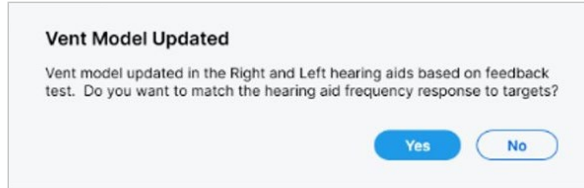

Figure 2. Example pop-up notification following FBC initialization when an acoustic mismatch has been detected. In this example, the acoustic (vent) model is updated on both sides. The hearing care professional is asked whether they want hearing aid gains to be re-adjusted by the software to match targets.

When a change in acoustic-model parameters is called for, the hearing care professional is notified and asked whether they want the hearing aid gains to be adjusted so that the real-ear gains predicted with the updated acoustic-model parameters match the fitting targets *[Figure 2]*.

If the hearing care professional answers 'yes', the hearing aid gains are adjusted by applying Starkey Target Match algorithm. If the hearing care professional answers 'no', acoustic-model parameters and real-ear predictions are still updated, but the hearing aid programmed gains are left unchanged. Importantly, regardless of the hearing care professional's answer to the pop-up question, the applied vent-effect model will be updated to be more consistent with the measured in-the-ear vent effect.

After the vent model is updated, the suffix 'measured' is appended to the acoustic option displayed in the dropdown menu where all available acoustic options are listed in the Pro Fit fitting software *[Figure 3]*.

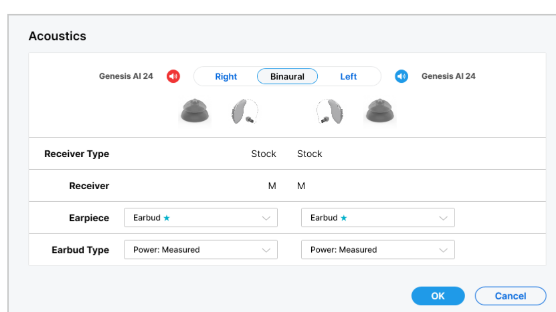

Figure 3. Whenever the vent model is updated based on FBC initialization data, the suffix 'measured' is appended to the selected acoustic option to indicate that the applied vent model was updated based on acoustic measurements.

To match or not to match?...

When should gains programmed into the hearing aid be adjusted to match targets, and when should they not be?

If fitting a patient with a new device, or restarting the fitting process from scratch, it will generally be desirable for hearing aid gains to initially match the targets for the selected fitting formula. Indeed, when starting a new fitting, the Target Match algorithm is applied automatically by default as part of Best Fit, so that the initial predicted real-ear gains match targets—to the extent possible within limitations imposed by electro-acoustic constraints. If a change is made that causes the predicted real-ear gains to be updated—for example, a different acoustic option is selected—Target Match must be re-applied, so that real-ear gains are again aligned with the targets. In this context, it is expected that most hearing care professionals will want Target Match to be applied after acoustic-model parameters have been updated by AMO.

By contrast, if FBC initialization is performed after hearing aid gains have already been manually adjusted by the hearing care professional and deemed satisfactory by the patient—as may happen on a follow-up visit or when reinitializing FBC on a device returned from repair on which FBC initialization data have been cleared—applying Target Match after AMO may be undesirable, as this will alter the programmed gains. In this context, the hearing care professional should answer 'no', when asked by the software, whether gains should be re-adjusted to match targets following FBC initialization. In this case, the acoustic model will still be updated based on FBC, but the programmed hearing aid gain will stay unchanged.

Whereas readjustments of hearing aid gains to match targets via the Target Match or Best Fit buttons are optional, the updating of acoustic-model parameters will happen automatically whenever called for by AMO. However, the hearing care professional always has the option of toggling AMO off *[Figure 4]*.

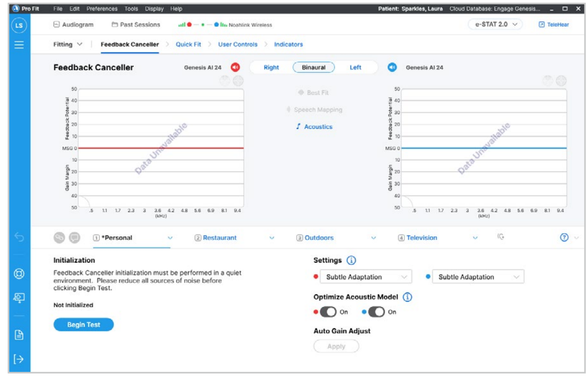

Figure 4. AMO toggle on FBC initialization screen. In this example AMO is ON. The fitting software systematically checks whether vent effects measured in the ear are consistent with the acoustic option selected in the fitting software. If a mismatch is detected, the hearing care professional is notified, and acoustic-model parameters (vent model) are updated to be more consistent with the in-situ measured acoustics.

In this case, acoustic-model updating by AMO will not occur. AMO will stay off until the toggle is manually turned back on.

Expected benefits

A first expected benefit of AMO is to warn the hearing care professional when a large mismatch is detected between the vent correction currently applied in the fitting software, and the in-situ measured vent effect. This is particularly useful on occasions where the professional has forgotten to update the acoustic options in the software after changing an earbud or earmold, or making changes to a custom device, e.g., altering a vent. While it is not recommended to rely solely on AMO to systematically eliminate such oversights, the feature can still help catch such occurrences.

Whenever an acoustic mismatch notification pops-up, and the hearing care professional realizes that they have forgotten to update acoustic options in the software, it is recommended to manually update acoustic options in the software so that they are correct, and to re-run FBC initialization with AMO. In some cases, by examining predicted real-ear responses or gains after running AMO, the hearing care professional may decide to change the physical coupling in the ear; for example, if an occluded dome is found to be less occluding in the ear than anticipated, and the low-frequency gain targets cannot be achieved, the professional may deem it best to use a power dome or a small-vent earmold instead.

A second expected benefit of AMO is to improve the accuracy of acoustic-model predictions, specifically, predicted real-ear responses and gains. To the extent that hearing care professionals, and the fitting software, rely on such predictions to adjust hearing-aid gains, having (more) accurate predictions is expected to facilitate the fitting process. Even if real-ear measurements with a probe-tube are subsequently performed, having a more accurate acoustic model to begin with, can be expected to reduce the number and magnitude of adjustments needed to match the real-ear targets.

An additional benefit of more accurate vent modeling relates to improved accuracy of hearing-threshold tests through the hearing aid using the in-situ audiometer in Pro Fit. This is because the in-situ audiometer leverages the acoustic model to estimate eardrum SPL during testing. Specifically, the audiometer adjusts the in-situ stimulus SPL to precisely compensate for sound leakage, so that the tone SPL at the eardrum is as intended. More accurate vent modeling is expected to result in more accurate in-situ threshold measurements *(Iverson and Micheyl, 2022).*

Clinical findings

The AMO feature was evaluated in a group of 73 participants with mild-to-moderately severe symmetric hearing loss. Of these, 32 were fitted bilaterally using Starkey Genesis AI RIC devices (16 RIC RT pairs, 16 mRIC R pairs) with standard domes (18 pairs Open, 9 pairs Occluded) or custom earmolds (4 pairs with Small vent, 1 pair with a Medium vent). The 40 other participants were fitted bilaterally using Genesis AI custom devices (9 pair ITE R, 11 pair ITCR, 10 pair CIC NW, 10 pair IIC NW), including 30 pairs with a Large vent, 8 pairs with a Medium vent, and 2 pairs with a Small vent.

AMO updated the acoustic model (starting from the clinician-selected acoustic option) for 35 out of the 73 participants. A greater proportion of model updates were observed with custom devices (25 out of 41 participants) than with RIC devices (10 out of 32 participants). For the latter, most of the updates occurred with occluded domes or earbuds; with open domes, an update occurred in only 1 out of 18 participants. More model updates for occluded domes or earbuds with medium or small vents than for open domes should be expected because vent effects are least variable for open domes [Figure 1]. Stated simply, it is extremely rare for an open dome to become substantially more occluded, and almost impossible for it to become substantially more open than it already is. In general, custom earmolds and custom devices have more variable acoustics than open domes.

To verify that AMO improves the accuracy of the acoustic model, in-situ and insert audiometry tests were performed following FBC initialization with AMO active. Because insert threshold measurements were used to provide reference (audiometric 'gold standard') data, they were performed in a sound booth according to audiological best practices. In-situ tests were performed in a moderately quiet test room, more typical of hearing aid fitting rooms outside of research laboratories.

Since the tone SPL of the in-situ audiometer in Pro Fit is set based on the acoustic model, in-situ threshold measurements are expected to be more accurate (i.e., closer to reference thresholds measured in the same ear) on average, when AMO is turned on than when it is turned off.

To check this, deviations between in-situ thresholds and insert thresholds measured in ears in whom the acoustic model was updated by AMO were compared to the thresholds that would have been measured, had AMO been turned off—the latter were estimated by subtracting from the measured in-situ thresholds, the acoustic-model change applied by AMO, thus effectively 'undoing' the impact of AMO on in-situ thresholds.

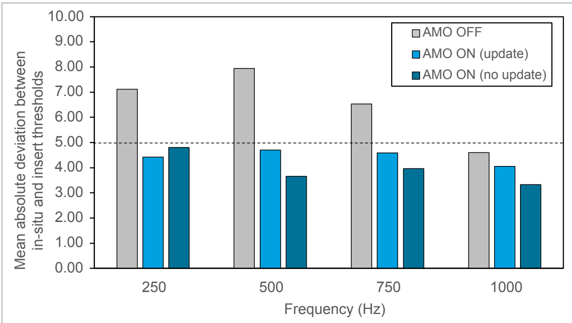

Figure 5. Mean absolute deviations between in-situ and insert thresholds with AMO OFF vs ON. For the latter case, separate bars show results for participants in whom AMO updated the acoustic model, vs participants in whom it did not. Results for the OFF condition refer to the former subgroup only. Dashed line: 5 dB corresponds approximately to the mean test-retest standard deviation for hearing thresholds across 250 – 750 Hz.

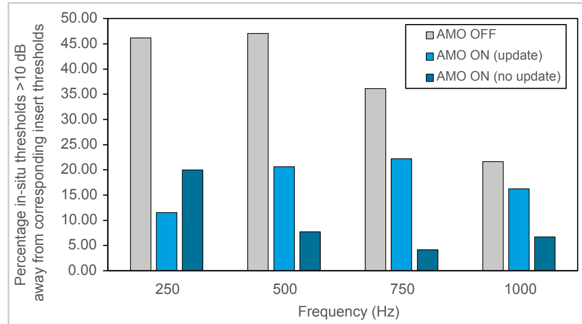

Figure 6. Percentage of in-situ measurements that deviated by more than 10 dB from the corresponding insert thresholds, with AMO OFF vs ON.

The results show that, for test frequencies below 1000 Hz, mean absolute deviations between in-situ and insert thresholds are larger when AMO is OFF than when it is ON *[Figure 5]*. For these three frequencies (250, 500 and 750 Hz) together, the difference between AMO OFF and AMO ON is statistically significant (Wilcoxson rank tests, P < 0.05).

Moreover, at these same low test frequencies, the percentages of measurements for which deviations between in-situ and gold-standard measurements exceeded 10 dB —a criterion commonly used in clinical audiology for declaring a significant difference in hearing thresholds (ASHA, 2015)— were found to be significantly larger with AMO OFF than ON *(Figure 6)*. For the 250 and 500 Hz test frequencies, the difference was statistically significant (Wilcoxon sign test, P>0.05).

For these analyses, data from participants whose insert thresholds at the test frequency were <= 20 dB HL were excluded; this was done to avoid truncated data and biased conclusions, due to in-situ measurements being limited to 20 dB HL or higher. With this exclusion criterion, results below are based on data from at least 40, and up to 74 ears, depending on the test frequency and subgroup (participants in whom AMO updated the acoustic model vs. participants in whom it did not).

Overall, these findings indicate that, by updating the acoustic model depending on the measured in-the-ear acoustics, AMO can significantly improve the accuracy of the acoustic model in the fitting software (SW) and consequently, the accuracy of in-situ threshold measurements.

Expected benefits for the hearing-aid user

While AMO is primarily aimed at helping hearing care professionals rapidly obtain individualized, and thus more accurate initial fittings, more accurate vent corrections may also benefit the hearing aid user.

This is especially the case for hearing aid users with low-frequency hearing loss. To provide these users with adequate gains at low frequencies, the impact of low-frequency sound leakage on the aided eardrum response must be accurately estimated. If the user has poorly fitting power domes or small-vent earmolds in the ears, and substantial low-frequency leakage is occurring, the actual eardrum SPL at low frequencies may be less than adequate.

This may manifest as lower-than-desired audibility, poorer-than-desired speech intelligibility, and worse-than-desired sound quality—less bass than expected based on predicted real-ear responses or gains, thus, less-full, sharper sounds than may be desirable.

Inadequate vent-effect corrections can also impact the listening experience of users who have little or no low-frequency loss, when using hearing aids to listen to streamed audio. In this situation, there is usually no external sound corresponding to the audio delivered by the hearing aid. To compensate for this, low-frequency components are automatically boosted by the hearing aid. The amount of low-frequency amplification applied in this mode, is determined based on the vent-leakage model. This effect is especially important for users for whom low-frequency gains are low to begin with—these users require more boosting of low-frequency sounds, than users for whom low-frequency sounds are already amplified by the hearing aids. By improving the accuracy of vent-effect corrections, AMO can lead to an improved listening experience during streaming.

FAQs

Why is it important to select the correct acoustic option in the fitting software?

Because AMO relies crucially on this piece of user-provided information when determining how to update the acoustic model. Moreover, for binaural fittings, the algorithm compares the acoustic options selected across sides and then uses different logic, depending on whether the left and right acoustic options are identical or different.

Whenever acoustic options selected for the left and right sides are identical, acoustic-model parameters are updated identically on both sides—so that, when starting with symmetric gain settings, the left and right responses and gains obtained after AMO has run, will remain symmetric.

When different left and right acoustic options are selected prior to initializing FBC, left and right gains and responses may not remain symmetric even if they were strictly symmetric to begin with.

Regardless of whether the fitting is binaural or monaural, professionals should always check that the acoustic option selected in the fitting SW matches the actual coupling option in the corresponding ear.

Why does AMO not always update the acoustic model even when the acoustic option selected in the fitting SW does not match the in-the-ear coupling?

For example, the algorithm will almost always update acoustic-model parameters when 'Power dome' is selected in the fitting software, while an open dome is in the ear. This is because the power dome is expected a priori by the acoustic model to yield a well-occluded fit, while the open dome is almost guaranteed to produce a large amount of leakage *[Figure 1]*.

By contrast, AMO is less likely to change acoustic-model parameters if 'Occluded dome' is currently selected in the fitting software, while an open dome is in the ear. This is because in some ears occluded domes can behave acoustically more like open domes than like an average occluded dome. In fact, in many ears, differences in the amount of sound leakage between an occluded dome and an open dome are not sufficiently large to warrant changing acoustic-model parameters.

By the same line of reasoning, acoustic-model parameters are least likely to be updated by AMO, when the acoustic option in the fitting software matches the acoustic coupling in the ear—unless the dome size selected provides a very poor fit to the individual's ear and results, for example, in slit leaks around a power dome making it no more occluding than an average open dome.

When should AMO be re-run?

FBC initialization should always be re-run after either or both acoustic options in the fitting software, or the acoustic coupling in at least one ear, is modified in some way.

A change in the acoustic coupling, such as changing from an open dome to an occluded dome, is likely to result in a change in the acoustic feedback path and in-situ vent effect therefore also, in the vent effect estimated by AMO. Thus, there are two good reasons to re-run FBC initialization and AMO in this situation.

Why does AMO sometimes modify the gain targets, not just the actual gains?

While a vent-model update following AMO will always be accompanied by an adjustment of predicted hearing-aid gains and responses, it should not be expected to impact targets. This is because real-ear targets, as defined in most fitting formulas (including NAL-NL2) are independent of the acoustic coupling, including, vent effects (see Dillon, 2012). Consistent with this, for most fitting formulas, targets will remain unchanged after AMO has been run, even when the acoustic model has been updated.

One exception to this is, when using Starkey's proprietary fitting formula (e-STAT 2.0). This formula includes logic whereby, for all but fully occluded fittings, targets are adjusted to minimize interactions between amplified and direct sounds—interactions that can produce undesirable psychoacoustic effects, such as 'comb-filtering' artifacts. Because this logic depends on modeled vent effects, it readjusts targets after any change in applied vent corrections, whether triggered by AMO or by a manual change of acoustic option.

When should AMO be turned off, if ever?

Opting out of AMO may be useful in some situations; for example: when re-running FBC initialization to help confirm a receiver or microphone issue. A damaged or plugged microphone or receiver, can make it appear as if substantially less feedback is occurring, compared to a well-functioning device. As explained above, AMO uses feedback measurements to estimate sound leakage. Thus, abnormal acoustic-feedback path measurements can interfere with the functioning of AMO and result in (a) improper acoustic-model parameter updates, and (b) inaccurate predictions of real-ear responses and gains.

As a rule, FBC initialization should not be performed while the hearing aid is either not in place, or improperly positioned, within the user's ear. This includes testing in a coupler. If FBC initialization must be performed under such circumstances, then AMO should first be turned off—it can always be turned back on later, prior to running FBC initialization in the user's ear. If not, there is a risk that an incorrect vent model will be applied.

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Author Biographies

Christophe Micheyl holds a PhD in Psychology and a Hearing-Aid Dispenser Diploma from the University of Lyon, France. His main areas of expertise include psychoacoustics, auditory neuroscience, and hearing aids. Prior to joining the Starkey Hearing Science Research Center in 2013, he held researcher/professor positions in various academic institutions in France (CNRS), the UK (Cambridge University) and the USA (MIT, University of Minnesota). He has coauthored 140 peer-reviewed publications in scientific journals and several book chapters on topics ranging from speech and music perception to auditory neuroscience and tinnitus, plus a few patents. He is currently a Senior Principal Scientist in Starkey's Advanced Development department and affiliated with Starkey France.

Jumana Harianawala currently works as a Senior Fitting Systems Design Engineer at Starkey in Eden Prairie, Minnesota. She specializes in and is responsible for improving hearing aid fittings and adaptations using progressive concepts & techniques like environment momentary assessment-based tuning. Jumana joined the Starkey team in 2011 and worked on qualitative and quantitative research investigating benefits from innovative technologies that lead to the development of new features and products. Prior to joining Starkey, Jumana lived in New York and worked as a practicing audiologist at an ENT clinic to gain a better understanding of the needs of the hearing aid wearer before pursuing her research career.

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. As a Senior Signal Processing Research Engineer at Starkey he passionate about improving the next generation of hearing aids and applying his expertise in feedback reduction, dynamic range compression and ear canal acoustics.

Laura Woodworth, Au.D. joined Starkey in 1996 and has worked in various roles including customer relations, clinical audiologist, trainer and product management. Her passion to represent the voice of the customer complements her current role as Principal Product Manager where she specializes on improvements to the fitting software and TeleHear features. Under her guidance, multiple features and improvements have been introduced to the fitting software over several product launches and TeleHear has expanded its reach and scope beyond its initial introduction. She is particularly interested in refining and releasing software features that help hearing care professionals improve their patient journey.

Author Biographies (Continued)

Meg Introwitz-Williams holds a Bachelor of Arts in Speech-Language-Hearing Sciences from the University of Minnesota, Twin Cities, and a Bachelor of Science in Software Development from Western Governors University. She joined Starkey in 2021 as a Software Engineer with a focus on the development and verification of acoustic modeling and fitting prescription algorithms and has a passion for the intersection of rehabilitative audiology and engineering.

Maddie Olson, Au.D. joined Starkey as a Research Audiologist in 2021, and earned her Au.D. at the University of Wisconsin - Madison. She organizes product validation efforts to evaluate hearing technologies prior to market release, ensuring patients' needs are being met. Additionally, Dr. Olson evaluates device efficacy over the lifetime of hearing aids, allowing for longitudinal assessment of patient benefit, through post-market studies. She is particularly interested in areas of research that help to investigate long-term, positive patient outcomes for hearing aid users.

Sarah Iverson, Au.D., CCC-A, joined Starkey in 2021 as a Research Audiologist. She earned her B.A. at the University of Minnesota and her Au.D. at Northwestern University in Illinois. Her work at Starkey covers clinical validation of hearing aids prior to market release. Dr. Iverson works to include clinically relevant outcome measures in her research. Other areas of interest include competitive benchmarking and product usability, with the goal of ensuring hearing aids are meeting patient needs.

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