Starkey's In-situ Audiometer: Greater flexibility, improved accuracy

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Executive summary

- With Inspire X 2022.1, Starkey's in-situ audiometer has improved.
- The updated feature provides increased flexibility, allowing testing of frequencies below 1 kHz when fitting standard (Receiver-in-Canal or Behind-the-Ear) hearing aids with open domes.
- Moreover, the updates provide improved measurement accuracy over previous versions of Inspire, as reflected in smaller mean deviations between in-situ thresholds and reference thresholds (conventional audiometric measurements).
- Lastly, the range of testable tone levels shown on the in-situ audiometer screen now changes based on the selected device style, receiver strength, and acoustic coupling option.

Background

In-situ audiometry has been gaining popularity among hearing professionals in recent years. The main purpose of the in-situ audiometer feature in Starkey's fitting software, Inspire X, is to allow hearing professionals to measure hearing thresholds through a hearing aid, without needing to use dedicated audiometric testing equipment. This can save time during in-person visits and is especially advantageous during remote hearing aid fitting sessions.

Though not intended as a replacement for hearing loss diagnosis using conventional audiometry, the in-situ audiometer can provide hearing professionals with a quick, convenient, and reliable tool to measure hearing thresholds beyond the initial hearing loss diagnosis. This tool can be easily accessed through the fitting software during follow-up and remote consultations, to help detect changes in an individual's aided perception, whether caused by changes in the hearing aid performance, its coupling to the ear (e.g., changing the dome size), or the user's hearing sensitivity (to be confirmed using conventional audiometry).

Compared to the headphone or insert earphone, in-situ measures reflect the acoustic coupling of the hearing aid to the individual's ear, including effects such as venting (loss of sound energy outside of the ear canal), and residual-cavity volume (depending on earmold or dome insertion depth), both of which can influence sound pressure level (SPL) at the eardrum. Deviations of in-situ measures from reference measures can alert hearing professionals to the existence and magnitude of differences between expected and actual eardrum SPL. Starkey's fitting software, Inspire X, uses a mathematical model to estimate (predict) the influence of venting and other acoustic-coupling effects on eardrum SPL for fittings, depending on the selected device style and acoustic options. The in-situ audiometer algorithm uses this model to address the aforementioned deviations. However, prior to Inspire X 2022.1, this model was not used to its full potential in the in-situ audiometer module.

As a result, the range of in-situ testable frequencies was limited to above 0.75 kHz when using open domes with standard hearing aids, and large (>15 dB) deviations between in-situ and conventional audiometric measurements could be observed with occluded or power domes and custom devices with large vents.

By updating the algorithm behind the in-situ audiometer in its latest release, Starkey is improving the accuracy of in-situ threshold measures for all product families using Inspire. Additionally, with this updated algorithm, hearing professionals can test over a greater frequency range with the in-situ audiometer, with standard hearing aids fitted with open domes—one of the most popular fitting styles, to date (Picou, 2020).

In this article, we explain what changes have been made to the in-situ audiometer in the latest Evolv AI release, why these changes have been made, and how they result in substantial improvements in the accuracy of in-situ threshold measures for Starkey's standard and custom products, compared to earlier versions of Starkey's in-situ audiometer.

Starkey's updated in-situ audiometer algorithm: what changed, and why

The main change of the in-situ audiometer relates to the computation of the in-situ test-tone sound pressure level (SPL). In the original in-situ audiometer feature (hereafter referred to as the 'legacy' feature), test-tone SPL was set based on reference equivalent threshold SPLs (RETSPLs) for insert earphones in a 2-cc coupler. While facilitating verification of output SPLs in a 2-cc coupler, this design characteristic limited the accuracy of threshold measurements, especially at low frequencies (<1 kHz) and for open domes, which usually yield large vent-out effects, or leakage. Accordingly, when the acoustic option selected in the fitting software was 'open domes', in-situ testing at low frequencies was disallowed.

Starting with Inspire X 2022.1, the in-situ audiometer removes this limitation by automatically setting test-tone SPL in relation to the chosen acoustic coupling option. The tone SPL is adjusted in an attempt to compensate for acoustic-coupling effects on the estimated eardrum SPL. As demonstrated in the next section, the new level-setting algorithm results in more accurate measurements, especially at low test frequencies and with open domes or large vent custom products.

While these improvements to the in-situ audiometer algorithm occur inside the software, two other improvements will be visible to users of Inspire X who were already familiar with the user interface (UI) of Starkey's in-situ audiometer. Firstly, the updated user interface now allows testing below 1 kHz for standard products with open domes, which adds flexibility in testing for this popular fitting style. Secondly, the maximum tone levels that can be tested in-situ (bottom contour of the testable range shown on the screen) are now adjusted automatically, based on the selected acoustic option. The maximum tone level that can be produced at the eardrum by the hearing aid receiver depends on how the aid is coupled to the ear. Thus, for example, for the same receiver model, the highest in-situ tone level that can be tested with will be lower when using an open dome (large vent effect) than when using a power dome (smaller vent effect, on average). *For this reason, it is particularly important that the acoustic option selected in the fitting software always matches the acoustic coupling in the ear.*

Clinical study

Results of a clinical study comparing Starkey's updated and legacy in-situ audiometer features demonstrate improvements in threshold-measurement accuracy, as described below.

Participants: Twenty-five individuals (13 males, 12 females; mean age: 68.1 years; range: 36.6 to 86.8 years) with primarily sensorineural hearing loss (see mean audiometric data in Figure 1), all experienced hearing aid users (defined as six or more months of full-time hearing aid use), participated in the study. Twelve were fitted with Receiver-in-Canal (RIC) hearing aids. The remaining twelve were fitted with custom devices, including Completely-in-Canal (CIC) (N = 4), In-the-Canal (ITC) (N = 5), and In-the-Ear (ITE) (N = 4) hearing aids.

Methods: In-situ audiometry testing was conducted in a quiet room. Each participant was tested both with Evolv AI hearing aids with the legacy in-situ audiometer (Inspire X 2021.0), and with the updated in-situ audiometer (Inspire X 2022.1). Hearing aids were inserted into the participants' ears by an audiologist.

RIC hearing aid participants were each tested with the updated and legacy in-situ audiometers using open, occluded, and power domes. Since measurement variability due to acoustic coupling is usually worse with occluded or power domes (compare sizes of error bars at low frequencies for 'open' vs 'power' or 'occluded' in Figures 2 and 3 below), test-retest measurements were made only for the power domes.

Custom hearing aid participants were tested with the updated and legacy in-situ audiometers using the vent size recommended in Inspire X based on their hearing loss. Thus, the vent size breakdown was as follows: large (2.7 mm and larger; N = 4), occluded (1.9-2.6 mm; N = 5), or small (0.5-1.8 mm; N = 4). For each participant, test-retest measurements were made.

In-situ thresholds were compared to 'reference' thresholds measured in the same ear, using standard insert earphones (Etymotics, ER-3A), with the participant inside an audiometric booth. All hearing threshold tests were performed in accordance with the modified Hughson-Westlake procedure (Carhart and Jerger, 1959). Conventional audiometric test frequencies between 250 and 8000 Hz, including inter-octaves (750, 1500, 3000, and 6000 Hz) were tested, for both ears (left and right).

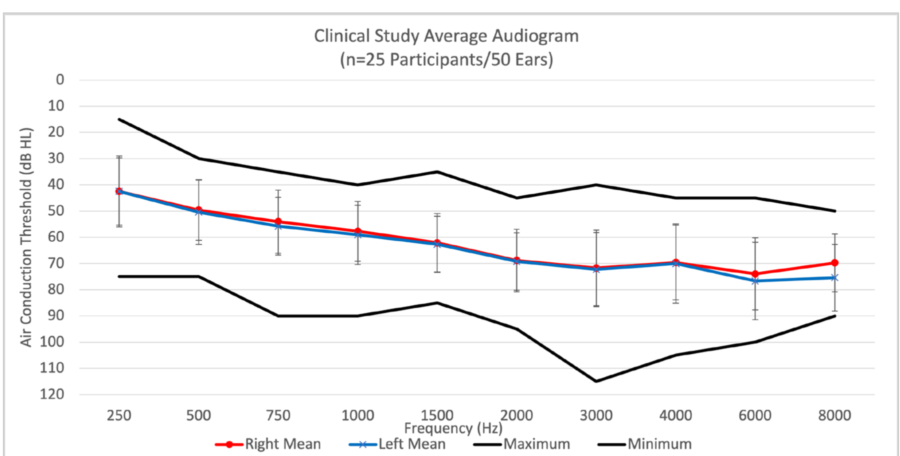

Figure 1: Pure-tone air conduction thresholds measured using insert earphones in sound booth, averaged across all participants in the clinical study (N = 25). Red symbols represent average thresholds for the right ear and blue symbols represent average thresholds for the left ear.

Results

Performance of the updated and legacy in-situ audiometer features was quantified using mean measurement errors, computed as mean deviations between in-situ and reference audiometric (insert) thresholds. As is customary in measurement-error analysis, deviations were squared prior to averaging. The resulting measures are referred to as root-mean-square errors (RMSEs).

Figure 2 shows RMSEs for the legacy feature versus the updated feature. Bar height reflects the magnitude of the deviation between in-situ and reference (insert) thresholds: the higher the bar, the larger the deviation (on average), i.e., the larger the measurement error.

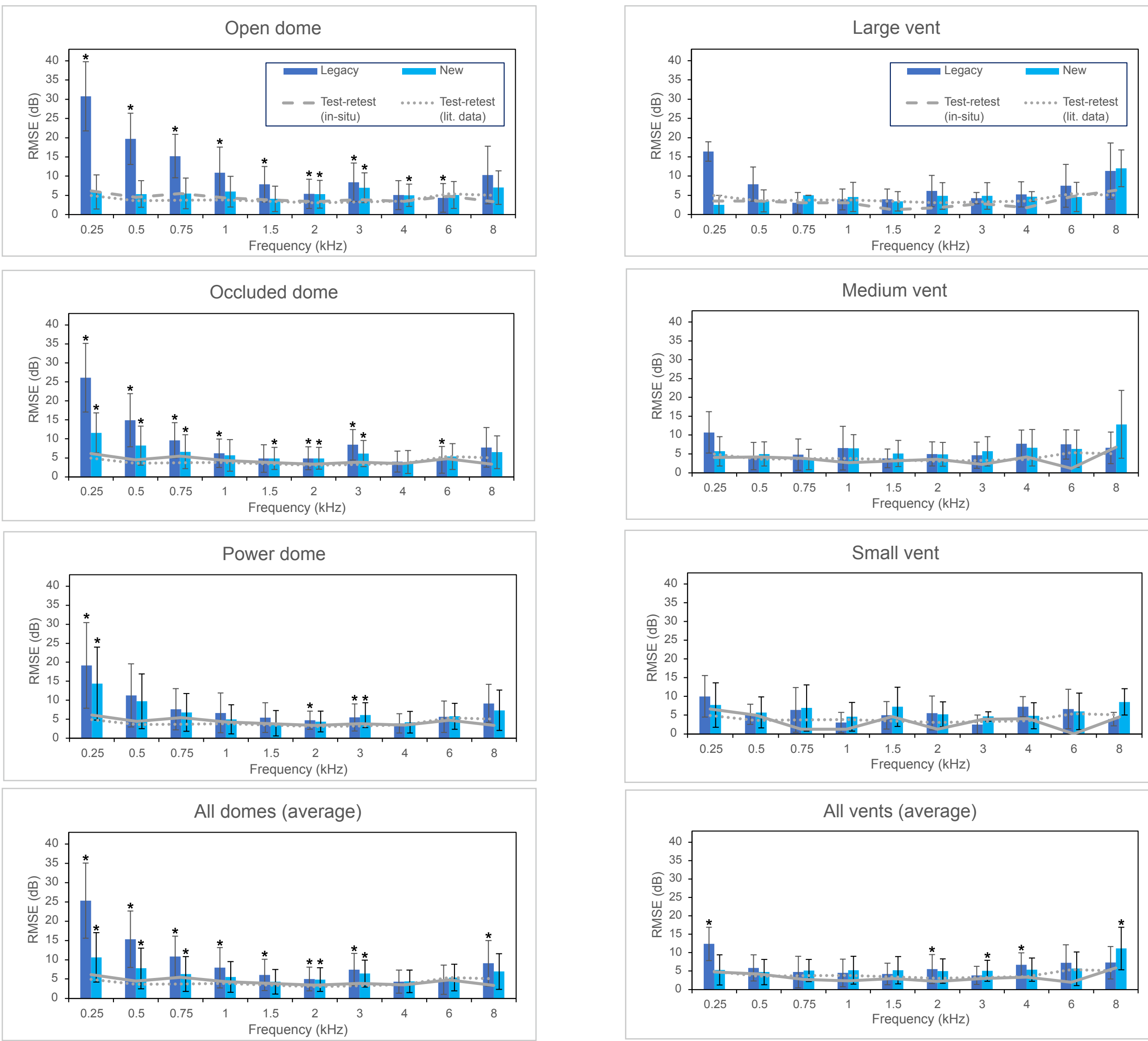

Figure 2. Mean in-situ measurement errors (RMS deviations between in-situ and reference hearing thresholds) for the legacy feature and the updated feature. Navy-blue bars: legacy feature. Light-azure bars: updated feature. Left: RICs with various dome types (Open dome; Occluded dome; Power dome); the panel labeled 'All domes' shows results averaged across all dome types tested. Right: custom hearing aids with various vent sizes (Large vent; Medium vent; Small vent); the panel labeled 'All vents' shows results averaged across all tested custom devices. Dashed lines: mean test-retest deviations from this study. Dotted lines: mean test-retest deviations from the literature. Asterisks: statistically significant average differences between in-situ measurement errors and test-retest errors, on average.

As shown in Figure 2, measurement errors were often larger with the legacy feature than with the updated feature. This was the case especially for open domes at frequencies below 1 kHz. For example, at 250 Hz, the RMSE in this situation was about 30 dB. In clinical practice such large deviations would never be observed with the legacy feature, since testing of frequencies lower than 1 kHz was not allowed when the acoustic option selected in the fitting software was an open dome.

By comparison, RMSEs measured at low frequencies with open domes using the updated feature are much lower. In fact, they are not statistically significantly higher than the mean test-retest error (Wilcoxon signed-rank test). This finding supported the decision to allow in-situ testing below 1 kHz with open domes in the updated feature. Test-retest errors are shown in Figure 2 using dashed and dotted lines, where the former show test-retest RMSEs from this study while the latter show, for comparison test-retest standard deviations averaged across published datasets (Brown, R., & Dickson, 1948; Robinson, 1960; Atherley & Dingwall-Fordyce, 1963; Pugsley et al., 1993); as can be seen, test-retest errors in this study matched the literature data well.

With the legacy feature, RMSEs were smaller for occluded and power domes than for open domes, consistent with smaller low-frequency vent effects for the former than for the latter, on average. By the same token, RMSEs at 250 Hz were often smaller than the corresponding-frequency RMSEs for RICs. With smaller measurement errors in the legacy feature to begin with, there was less room for improvement in the updated feature, for these fitting options.

To make it easier to appreciate the magnitude of improvements in measurement accuracy, upward-pointing bars indicate a reduction in measurement error, i.e., an improvement in measurement accuracy, when going from the legacy to the updated feature; negative values indicate the converse.

Statistically significant improvements (indicated by asterisks, determined using Wilcoxon signed-rank tests) were observed for the lowest (0.25 kHz) test frequency for all domes types, as well as for custom hearing aids after combining data across all vent sizes tested (N = 13, bottom panel). For open and occluded domes, statistically significant improvements were also observed at 0.5 and 0.75 kHz, and up to 1.5 kHz for open domes. Marginal improvements were also observed at 3 kHz with occluded domes and 6 kHz with customs after combining data across all vent sizes. At 8 kHz, RMSEs were visibly higher with the updated than with the legacy feature for custom devices. Although the difference failed to reach statistical significance, even after combining data across all vent styles, we recommend that caution be exercised when interpreting 8 kHz thresholds measured in-situ. Eardrum SPL at high frequencies can be quite variable across ears and devices, and thus difficult to predict accurately. Consequently, at these high frequencies, the acoustic model used inside the in-situ audiometer feature may yield less accurate results. In-situ thresholds should always be compared against conventional audiometric thresholds.

To summarize, in several of the conditions tested in this study, in-situ measurement error was found to be significantly reduced, on average, when using the updated feature. In the other test conditions, measurement error was not statistically significantly different between the updated and legacy feature.

Lastly, although with the updated feature, RMSEs were above test-retest errors for several of the frequencies tested, in most cases, the difference was less than 5 dB. Two exceptions to this are for occluded or power domes at 250 Hz, as well as for a few higher frequencies (3 kHz for RICs and 6 and 8 kHz for customs). These residual measurement errors may reflect inter-individual variations, or lesser occlusion by occluded and power domes, than predicted by the model.

Thus, although the updated feature improves greatly over the previous one, deviations between in-situ and conventional audiometry test results that exceed test-retest variability can still occur and must be considered by hearing professionals when responding to sound quality or performance feedback from patients fitted with gains computed based on in-situ measurements.

Overall, Starkey's updated in-situ audiometer feature, introduced in the updated Evolv AI family and Inspire X 2022.1, provides substantial improvements, with reduced measurement errors, especially at low frequencies (<1 kHz) for standard hearing aids with open or occluded domes, two of the most widely used fitting configurations today.

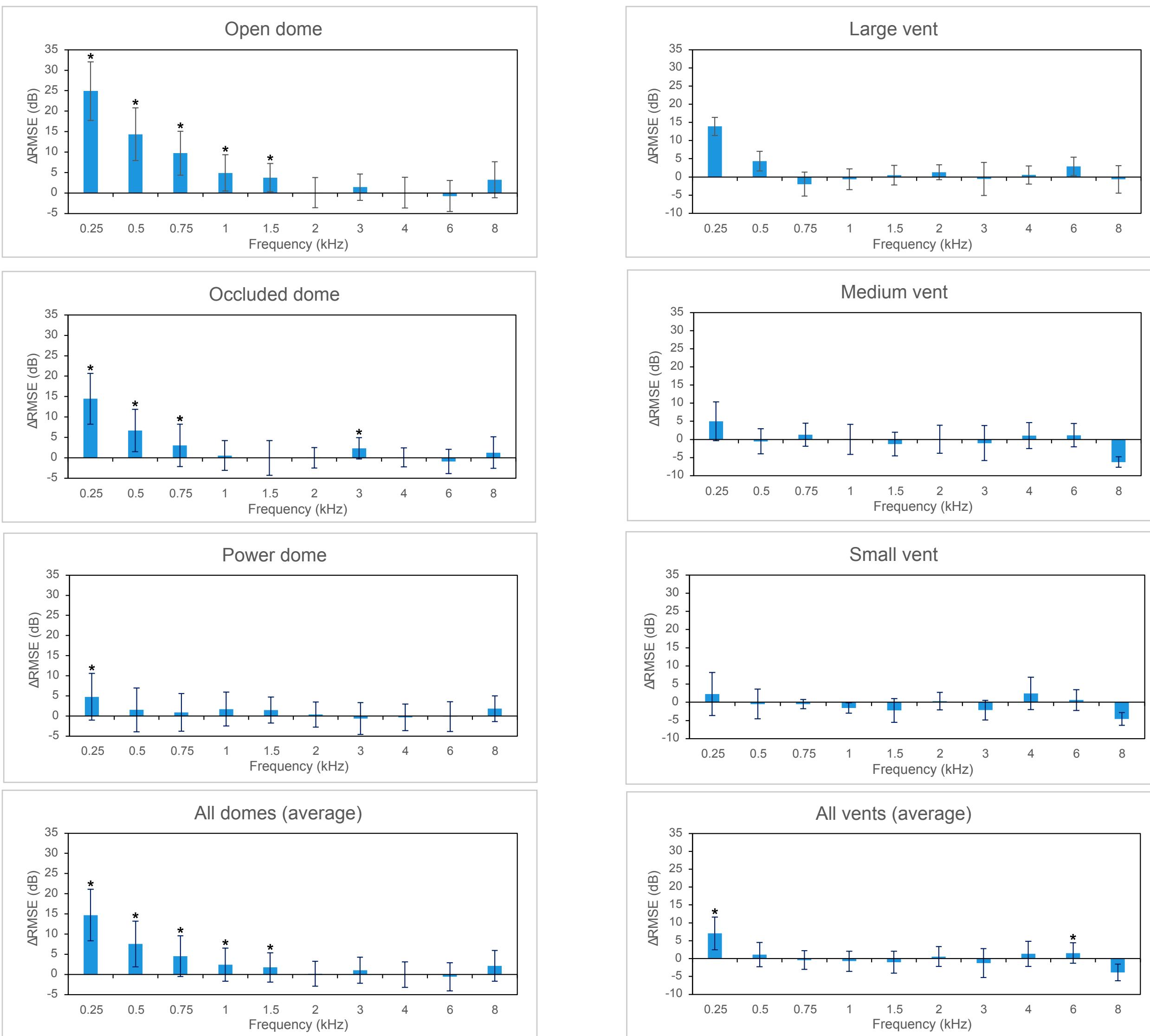

Figure 3. Mean differences in RMSE between the legacy and updated features. Left: RICs with various dome types (Open dome; Occluded dome; Power dome); the panel labeled 'All domes' shows results averaged across all dome types tested. Right: custom hearing aids with various vent sizes (Large vent; Medium vent; Small vent); the panel labeled 'All vents' shows results averaged across all tested custom devices. Asterisks indicate statistically significant differences, tested using Wilcoxon signed-rank tests comparing RMSEs averaged across the left and right ears, between the legacy and updated features.

Summary

- Starting with Inspire X 2022.1, Starkey's in-situ audiometer has improved.
- The updated in-situ audiometer automatically adjusts test-tone SPL depending on the acoustic option (dome type or vent diameter) selected in the fitting software.
- In-situ thresholds measured using the updated feature are closer (on average) to reference audiometric hearing thresholds measured using insert earphones in a sound booth.
- Moreover, with the updated feature, measurement errors (quantified as root-mean-squared deviations between in-situ and insert thresholds) are often within 3 dB of test-retest errors.
- These improvements are available with all product families fitted using Inspire X 2022.1.
- The in-situ audiometer feature can be used by hearing professionals during remote or in-person visits.
- In-situ audiometry may be used to measure hearing thresholds through the hearing aid for the purpose of fitting hearing aids or for tracking changes in in-situ hearing thresholds over time, but should not be used as a substitute for standardized audiometric equipment for hearing loss diagnosis purposes. In-situ thresholds are specific to the acoustic coupling of the hearing aid and individual ear and can be influenced by the environment in which the testing is conducted, and should not be considered a replacement for diagnostic audiometric results.

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