Advancing Audiometric Precision: Mastering Kuduwave's SPHLin-ear with Standardised MPANL Correction Factors

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Abstract

Background: Ambient noise presents a persistent challenge to the accuracy of audiometric evaluations, particularly in settings outside traditional sound-attenuating booths. The Kuduwave audiometer is engineered to address this challenge through a sophisticated real-time ambient noise monitoring system.
Objective: This white paper elucidates the interpretation of the Kuduwave's "Noise in ear canal (External mic) dB HL" (SPHLin-ear - Sound Pressure Hearing Level in the ear canal) metric, a critical indicator of noise levels within the patient's ear canal, referenced to audiometric zero. It details an advanced 4-step calculation for this metric, incorporating a crucial internal +3dB Sound Pressure Level (SPL) recording safety offset and Maximum Permissible Ambient Noise Level (MPANL)-standard-specific correction factor. A key aspect is that Kuduwave-specific MPANLs, used for deriving these correction factors, are now sourced from the definitive GeoAxon guide: "Establishing Maximum Permissible Ambient Noise Levels for the Kuduwave Audiometer: A Guide for Clinical, Research, and Proposed Unified Global Applications" This paper aims to detail the derivation of corresponding "Noise in ear canal (External mic) dB HL" correction factors for ANSI S3.1, ISO 8253-1, and SANS 10182 standards, for both foam and silicone eartips.
Methods: The methodology involves applying the Kuduwave's 4-step "Noise in ear canal (External mic) dB HL" calculation framework, which includes the internal +3dB SPL offset. MPANL-standard-specific correction factors are derived by utilizing the

Kuduwave MPANLs sourced from the aforementioned external GeoAxon guide. These derivations are performed for ANSI S3.1, ISO 8253-1, and SANS 10182 standards, considering both foam and silicone eartip configurations.
Results: The derived "Noise in ear canal (External mic) dB HL" correction factors are presented in comprehensive lookup tables. Furthermore, this paper explains the Kuduwave's enhanced real-time noise display features, its peak noise monitoring methodology, and introduces the concept of "Minimum Plateau Threshold" annotation.
Conclusion: The principles and calculations detailed herein are of significant consequence for advancing boothless audiometry. They serve to enhance diagnostic confidence and expand the reach of reliable hearing assessments, positioning the Kuduwave system as a pivotal tool in modern audiology.

1. Introduction: The Imperative of Precise Noise Management in Modern Audiometry

The accuracy of pure-tone audiometry, the gold standard for quantifying hearing sensitivity, is fundamentally reliant on a sufficiently quiet test environment.[1] Ambient noise, if not adequately controlled or accounted for, can mask the pure-tone stimuli, leading to erroneously elevated hearing thresholds and potentially misdiagnosis or inappropriate management. This challenge is particularly acute in environments outside conventional, sound-attenuating audiometric booths. The global demand for hearing healthcare services is escalating, necessitating more accessible and versatile testing solutions, including boothless audiometry. While offering logistical and cost advantages, boothless systems inherently face higher and more variable ambient noise levels, heightening the risk of compromised test validity.[1]

The Kuduwave audiometer represents a significant advancement in addressing these challenges. It is a sophisticated, portable diagnostic audiometer engineered for accurate audiometric testing across a wide range of environments, including those where ambient noise is a concern. A cornerstone of the Kuduwave's capability is its integrated, real-time ambient noise monitoring system, which provides clinicians with crucial information about the acoustic conditions at the point of care. This system's innovation is partly rooted in the principles outlined in the PCT patent WO2008139404A1, which describes methods for in-ear noise monitoring to enhance audiometric accuracy in varied environments.[1]

This white paper details the methodology for calculating and interpreting the Kuduwave's "Noise in ear canal (External mic) dB HL ($SPHL_{in-ear}$)." This includes a comprehensive explanation of an internal $+\ 3dB\ SPL$ recording offset applied to the external microphone measurements before calculating in-ear dB HL, and the introduction of MPANL-standard-specific correction factors. A pivotal update in the methodology presented here is that these correction factors are derived based on Kuduwave-specific Maximum Permissible Ambient Noise Levels (MPANLs) that are sourced from an external, comprehensive guide.[1] This paper will focus on the application of these principles for ANSI S3.1-1999 (R2018), ISO 8253-1:2010, and SANS 10182:2006 standards, considering both foam and silicone eartips. The Kuduwave system offers flexibility by allowing users to select from various MPANL standards, ensuring the device can meet diverse regulatory requirements or clinical preferences by tailoring its noise assessment to the chosen benchmark.[1]

2. Kuduwave's External Microphone System and Internal Processing

The Kuduwave's capacity for reliable audiometry in varied acoustic settings is critically dependent on its external microphone system and subsequent internal processing of the measured ambient noise. These features are designed for accurate measurement and a conservative interpretation of ambient noise, particularly when deriving the clinically relevant $SPHL_{in-ear}$ metric.

2.1. Accurate Ambient SPL Measurement

The Kuduwave features an external microphone on each earcup. This microphone is tasked with measuring the actual ambient Sound Pressure Level ($SPL_{actual\_ambient}$) in the immediate vicinity of the ear being tested. These microphones undergo calibration using an acoustic calibrator during the device's annual calibration procedure, adhering to work instructions specified by GeoAxon. The inherent measurement error of these microphones is specified by GeoAxon to be less than $\pm\ 3dB$.[1] The Kuduwave displays this $SPL_{actual\_ambient}$ in real-time to the user, providing a direct physical measure of the noise energy in the environment.[1]

2.2. The Internal $+\ 3dB\ SPL$ Offset: A Conservative Approach for In-Ear HL Calculations

A pivotal feature of the Kuduwave's ambient noise assessment, specifically for the calculation of $SPHL_{in-ear}$, is the internal application of a $+\ 3dB\ SPL$ offset to the measured $SPL_{actual\_ambient}$. This means that the ambient sound pressure level used by the system for its internal calculations of in-ear dB HL, termed $SPL_{ambient\_recorded}$, is effectively $SPL_{actual\_ambient}\ +\ 3dB$.[1] This $SPL_{ambient\_recorded}$ is not what is directly displayed to the user as the ambient SPL; the user sees the $SPL_{actual\_ambient}$ in real time.

This internal $+\ 3dB$ offset is a deliberate design choice rooted in a conservative engineering philosophy. By treating the ambient noise as 3dB louder than it actually is for the purpose of deriving the in-ear dB HL value, the system incorporates a significant safety margin into this critical derived metric. This approach serves multiple purposes [1]:

1. **Compensating for Potential Microphone Variability in HL Calculation:** While the microphones are calibrated to a high degree of accuracy, the internal $+\ 3dB$ offset proactively accounts for the maximum potential positive measurement error when calculating the in-ear dB HL.
2. **Ensuring High Confidence in MPANL Compliance via In-Ear HL Display:** When the Kuduwave's $SPHL_{in-ear}$ display indicates that the test environment is quiet enough according to a selected MPANL standard, this assessment is made based on calculations that used the $SPL_{ambient\_recorded}$. Therefore, if the system determines compliance even with this internal 3dB "penalty" in its HL calculation, there is a very high degree of confidence that the actual ambient noise is well within the permissible limits of the standard.
3. **Approaching "Certification-Level" Assurance for Test Environments via In-Ear HL Display:** The combination of precise earcup attenuation, accurate RETSPL/ETSPL data, and this conservative internal $+\ 3dB$ offset in the HL calculation allows the Kuduwave's in-ear dB HL display to assess whether an environment is "quiet enough" with a level of assurance that approaches what is typically expected when using a Class 1 Sound Level Meter (SLM) for certifying a room against MPANL standards.

This meticulous and cautious approach to the calculation of in-ear noise levels underpins the Kuduwave's reliability for boothless audiometry, ensuring that the system errs on the side of patient safety and diagnostic accuracy when presenting the critical in-ear dB HL metric. This design philosophy aligns with findings from Swanepoel et al. (2015), which describe the Kuduwave's noise monitoring as "aggressive" in its effort to represent the highest potential noise levels, thereby ensuring conservative and reliable operation.[1] The $+\ 3dB$ offset is a foundational element of the $SPHL_{in-ear}$ calculation, working in concert with the $MPANL_{Correction\ Factor}$ (discussed in Section 5) to provide a robust assessment of the acoustic environment. Even if the actual ambient noise is precisely at the true MPANL, the system internally evaluates it as MPANL + 3dB, and the $SPHL_{in-ear}$ aims to reflect compliance under this more stringent internal condition.

3. Foundational Audiometric Principles for Kuduwave Noise Interpretation

A thorough understanding of core audiometric concepts is vital for interpreting the Kuduwave's noise data and the methodologies outlined in this paper. These principles form the basis for converting physical sound measurements into clinically relevant hearing levels and for understanding how the Kuduwave system manages ambient noise.

3.1. Sound Pressure Level ($dB\ SPL$): The Physical Measure of Sound

Sound Pressure Level ($dB\ SPL$) is an objective, physical measure of sound intensity, expressed in decibels (dB) relative to a reference sound pressure of 20 micropascals (µPa). This reference approximates the average human hearing threshold at 1000 Hz. The formula is $L_p = 20log10(\frac{P}{P_0})$, where L_p is the $dB\ SPL$, P is the measured RMS sound pressure, and P_0 is the reference pressure.[1] The Kuduwave's external microphone measures ambient noise in $dB\ SPL$, and this actual measured value ($SPL_{actual\_ambient}$) is displayed to the user.[1]

3.2. Hearing Level (dB HL): The Normative Clinical Standard

Hearing Level (dB HL) is a normative scale used in audiometry, referencing hearing sensitivity to "audiometric zero," which is the average threshold of otologically normal young adults at each frequency. This scale simplifies audiogram interpretation by "flattening" the normal hearing curve, making deviations from normal hearing readily apparent.[1] The Kuduwave displays in-ear noise ($SPHL_{in-ear}$) in dB HL for direct clinical relevance.[1]

3.3. Reference Equivalent Threshold Sound Pressure Levels (RETSPLs) and Equivalent Threshold Sound Pressure Levels (ETSPLs): Bridging $dB\ SPL$ and dB HL

RETSPLs (or device-specific ETSPLs) are standardized $dB\ SPL$ values corresponding to $0\ dB\ HL$ for specific frequencies and transducer-coupler combinations. They are essential for converting between the physical measurement of sound ($dB\ SPL$) and the clinical measure of hearing ($dB\ HL$L), using the relationship: Hearing Level ($dB\ HL$) = Sound Level ($dB\ SPL$) - RETSPL/ETSPL ($dB\ SPL$).[1] The accuracy of these values is paramount, as they directly influence the calculated $SPHL_{in-ear}$.

3.3.1. Kuduwave's Adherence to Standards: RETSPLs for Foam Eartips

The Kuduwave system utilizes foam eartips that are acoustically similar to ER-3A insert earphones. For these eartips, Kuduwave employs RETSPLs consistent with the ISO 389-2:1994 standard, when measured with an IEC 60318-4 occluded-ear simulator.[1] These values are detailed in Appendix A, Table A1. This adherence ensures alignment with established audiometric practices for insert earphones.

3.3.2. Kuduwave's Innovation: Determining ETSPLs for Silicone Tympanometer Probe Eartips

For silicone (rubber) eartips, often used with the Kuduwave Pro TMP model for combined audiometry and tympanometry, distinct ETSPLs are necessary due to their different acoustic coupling characteristics compared to foam eartips. GeoAxon, through research such as Ramatshoma et al. (2021), has established specific ETSPLs for the Kuduwave when used with silicone eartips, also determined using an IEC 60318-4 simulator.[1, 1] These values are detailed in Appendix A, Table A1. This dedicated research ensures calibration accuracy across all Kuduwave transducer configurations.

The notable differences in both RETSPL/ETSPL values and sound attenuation characteristics (discussed next) between foam and silicone eartips mean that the choice of eartip profoundly alters the in-ear acoustic environment. It is therefore imperative that the Kuduwave software is correctly configured for the eartip in use, as this selection dictates which set of acoustic parameters is applied in all subsequent calculations of in-ear noise.[1] Failure to do so would lead to erroneous $SPHL_{in-ear}$ readings and could compromise clinical decision-making regarding test validity.

3.4. The Critical Role of Sound Attenuation: Isolating the Ear

Sound attenuation is the reduction in sound intensity provided by the audiometric headset, which, in the Kuduwave's case, comprises the circumaural earcup and the occluding insert eartip (foam or silicone). This passive attenuation is crucial for boothless audiometry, as it minimizes the amount of ambient noise that reaches the patient's ear, thereby reducing its potential masking effect on test stimuli.[1] Attenuation is frequency-dependent, generally being more effective at higher frequencies.

3.4.1. Combined Attenuation: Kuduwave Earcup and Foam Eartips

The Kuduwave earcup combined with foam eartips provides substantial noise isolation. Empirically determined attenuation values for this configuration are sourced from Kuduwave Technical Specifications and research by Swanepoel et al. (2015).[1] Specific values are provided in Appendix A, Table A2. Foam eartips typically offer high attenuation due to their expansive seal within the ear canal, conforming to individual ear canal shapes.

3.4.2. Combined Attenuation: Kuduwave Earcup and Silicone Tympanometer Probe Eartips

When using silicone eartips, the combined attenuation characteristics differ from those achieved with foam eartips. These values are sourced from Kuduwave Technical Specifications and research by Ramatshoma et al. (2021).[1, 1] Specific values are provided in Appendix A, Table A3. Silicone eartips may offer different attenuation profiles, often providing less attenuation at lower frequencies compared to foam eartips, due to their more structured form and seal mechanism.[1]

The eartip-specific values for RETSPL/ETSPL and Combined Attenuation are fundamental variables in the calculation of $SPHL_{in-ear}$ and, consequently, in the derivation of the $MPANL_{Correction\ Factor}$s. Any imprecision in these foundational parameters would propagate, affecting the accuracy of the final $SPHL_{in-ear}$ value. Therefore, their careful determination and correct application within the Kuduwave system are essential for reliable noise assessment.

4. Deciphering $SPHL_{in-ear}$: The Kuduwave's In-Ear Noise Metric

The Kuduwave audiometer's capacity to facilitate accurate audiometry in diverse acoustic environments hinges significantly on its "Noise in ear canal (External mic) dB HL" metric, abbreviated as $SPHL_{in-ear}$. This metric provides a real-time, clinically relevant measure of the noise levels present within the patient's ear canal, referenced to audiometric zero.

4.1. Definition and Clinical Significance

$SPHL_{in-ear}$ is the Kuduwave system's primary indicator of the potential for ambient noise to interfere with audiometric testing. It quantifies the effective noise level at the eardrum in dB HL, considering the external ambient noise, the headset's attenuation properties, and the reference thresholds for normal hearing. Its clinical significance lies in its ability to inform the audiologist or tester whether the current noise conditions are acceptable for obtaining valid hearing thresholds at specific frequencies. A low $SPHL_{in-ear}$ value suggests a quiet in-ear environment suitable for measuring sensitive hearing thresholds, while a high value indicates that ambient noise may be masking the test tones, potentially leading to erroneously elevated thresholds.

4.2. The Advanced 4-Step Calculation of $SPHL_{in-ear}$

The Kuduwave system employs a sophisticated 4-step process to derive the $SPHL_{in-ear}$ value. This process meticulously accounts for the actual external ambient noise, the internal $+\ 3dB$ recording offset, headset attenuation, eartip-specific reference threshold levels, and an MPANL-standard-specific correction factor.[1] The calculation flow is as follows:

- **Step 0: Measure Actual Ambient SPL ($SPL_{actual\_ambient}$)**

  The external microphone on the Kuduwave earcup measures the $SPL_{actual\_ambient}$ in the octave band corresponding to the test frequency. This value is displayed in real-time to the user in $dB\ SPL$.1

- **Step 1: Internally Calculate Recorded Ambient SPL ($SPL_{ambient\_recorded}$)**

  For the internal calculation of in-ear dB HL, the system applies the conservative

$+\ 3dB$ offset to the measured external noise:

$$SPL_{ambient\_recorded}(dB) = SPL_{actual\_ambient}(dB)\ +\ 3dB$$

This $SPL_{ambient\_recorded}$ is used internally for all subsequent steps in deriving $SPHL_{in-ear}$ and is not directly displayed to the user.1

- **Step 2: Calculate In-Ear Noise SPL (SPL_{in-ear})**
  The system then calculates the noise SPL that effectively reaches the ear canal after passing through the attenuating headset (earcup and eartip):

$$SPL_{in-ear}(dB)\ = SPL_{ambient\_recorded}(dB)\ -\ Attenuation_{earcup+eartip}\ (dB)$$

  The Combined Attenuation (earcup+eartip) values are frequency-specific and differ for foam and silicone eartips, as detailed in Appendix A (Tables A2 and A3).1

- **Step 3: Calculate $SPHL_{uncorrected}$**
  The SPL_{in-ear} is first converted to an uncorrected Sound Pressure Hearing Level ($SPHL_{uncorrected}$).

$$SPHL_{uncorrected} = SPL_{in-ear}(dB)\ -\ RETSPL/ETSPL(dB)$$

  The RETSPL/ETSPL values are frequency- and eartip-specific, as detailed in Appendix A (Table A1).1

- **Step 4: Calculate Final $SPHL_{in-ear}$**

$$SPHL_{in-ear} = SPHL_{uncorrected} - MPANL_{Correction\ Factor}(dB)$$

The $MPANL_{Correction\ Factor}$ is crucial for normalizing the $SPHL_{in-ear}$ display relative to the chosen MPANL standard (e.g., ANSI S3.1, ISO 8253-1, SANS 10182). The derivation and values of this factor, based on MPANLs, are detailed in Section 5 of this paper.

This 4-step calculation provides a robust framework for quantifying in-ear noise. Steps 0, 1, 2, 3 to calculate of $SPHL_{uncorrected}$ are consistent system processes. The critical step addressed in this paper lies in the determination of the $MPANL_{Correction\ Factor}$ in the final part of Step 4, which relies on a standardized set of externally sourced Kuduwave MPANLs.

5. Derivation and Application of the $MPANL_{Correction\ Factor}$

The $MPANL_{Correction\ Factor}$ is an essential component in the calculation of $SPHL_{in-ear}$, serving to normalize the displayed in-ear noise level relative to the specific Maximum Permissible Ambient Noise Level (MPANL) standard selected by the user. This section details the methodology for sourcing the reference Kuduwave MPANLs and the subsequent calculation of these correction factors.

5.1. Sourcing Kuduwave Maximum Permissible Ambient Noise Levels (MPANLs)

For the purpose of calculating the $MPANL_{Correction\ Factor}$, and for general clinical reference regarding acceptable ambient noise conditions, this white paper utilizes Kuduwave Maximum Permissible Ambient Noise Levels (MPANLs) that are sourced directly from the comprehensive GeoAxon white paper: "Establishing Maximum Permissible Ambient Noise Levels for the Kuduwave Audiometer: A Guide for Clinical, Research, and Proposed Unified Global Applications".[1] These sourced MPANLs represent the maximum actual external ambient SPL ($SPL_{actual\_ambient}$) that the Kuduwave system can tolerate while still permitting accurate diagnostic testing down to $0\ dB\ HL$.

This approach ensures that the $MPANL_{Correction\ Factor}$ are based on a definitive and consistent set of Kuduwave-specific MPANLs, established through rigorous methodology as detailed in the aforementioned guide.[1] Appendix B of the current document provides a summary of these sourced Kuduwave MPANL values ($SPL_{actual\_ambient}$ for $0\ dB\ HL$ testing) for the ANSI S3.1, ISO 8253-1, and SANS 10182 standards, across both foam and silicone eartips, for the standard audiometric frequencies. This explicit sourcing from a dedicated MPANL document [1] streamlines the process and ensures that the $SPHL_{in-ear}$ calculations are aligned with the most current and validated device-specific noise limits.

5.2. Methodology for Calculating the $MPANL_{Correction\ Factor}$

The $MPANL_{Correction\ Factor}$ is defined as: the uncorrected in-ear dB HL ($SPHL_{uncorrected}$) that would be calculated if the internally used $SPL_{ambient\_recorded}$ were exactly equal to a reference Kuduwave-specified MPANL (itself expressed as an $SPL_{ambient\_recorded}$ value for the purpose of this calculation, derived from the chosen standards sourced $MPANL_{Kuduwave\_0dBHL\_SPL_{actual\_ambient}}$ and incorporating the system's internal $+\ 3dB$ offset) for that standard, frequency, and eartip type.[1]

The derivation of the $MPANL_{Correction\ Factor}$ for a given standard, eartip, and frequency proceeds as follows:

1. Obtain Sourced Kuduwave MPANL ($SPL_{actual\_ambient}$):
   Retrieve the $MPANL_{Kuduwave\_0dBHL\_SPL_{actual\_ambient}}$ for the specific standard, eartip, and frequency from Appendix B of this document.1

2. Calculate the reference $KuduwaveMPANL_{SPLrecorded}$ for correction factor derivation:
   This step establishes the internal SPL value the system would use if the actual ambient noise were at the sourced MPANL limit.

$$KuduwaveMPANL_{SPLrecorded\_for\_correction\_calc}(dB) = Sourced\ MPANL_{Kuduwave\_0dBHL\_SPL_{actual\_ambient}}(dB) + 3dB$$

This incorporation of the $+ 3dB$ offset is critical, as it aligns the correction factor with the Kuduwave's conservative internal processing.

3. Calculate SPL_{in-ear} at this reference $KuduwaveMPANL_{SPLrecorded}$:
   This determines the sound pressure level that would reach the ear canal under these specific MPANL conditions, after headset attenuation.

$$SPL_{in-ear\_at\_MPANL}(dB)$$

$$= KuduwaveMPANL_{SPLrecorded\_for\_correction\_calc}(dB) - Attenuation_{earcup+eartip}(dB)$$

   (Combined Attenuation ($Attenuation_{earcup+eartip}$) values are taken from Appendix A, Tables A2 and A3).

4. Calculate $SPHL_{uncorrected}$ at this MPANL (This is the $MPANL_{Correction\ Factor}$):
   This converts the $SPL_{in-ear\_at\_MPANL}$ to an uncorrected hearing level. This resulting value is, by definition, the $MPANL_{Correction\ Factor}$.

$$MPANL_{Correction\ Factor}(dB) = SPL_{in-ear\ at\ MPANL}(dB) - RETSPL/ETSPL(dB)$$

   (RETSPL/ETSPL values are taken from Appendix A, Table A1).

This streamlined methodology ensures that the $MPANL_{Correction\ Factor}$ accurately reflects the point at which the $SPHL_{in-ear}$ should read $0\ dB\ HL$ when the actual external ambient noise ($SPL_{actual\_ambient}$) is precisely at the Kuduwave's specified MPANL for $0\ dB\ HL$ testing [1], given the system's internal $+ 3dB$ processing offset.

5.3. Comprehensive MPANL Correction Factors for Kuduwave Audiometry

Applying the methodology described in Section 5.2, MPANL Correction Factors have been calculated for the ANSI S3.1, ISO 8253-1, and SANS 10182 standards, covering both foam and silicone eartips, across standard audiometric frequencies from 125 Hz to 8000 Hz. These values are presented in Table 1. This table is a central component of this white paper, providing the precise correction values necessary for the Kuduwave system to accurately calculate and display $SPHL_{in-ear}$ according to the selected standard and eartip configuration, based on the externally sourced MPANLs. The inclusion of intermediate calculation steps within the table enhances transparency and allows for verification of the derived factors.

Table 1: MPANL Correction Factors (dB) for $SPHL_{in-ear}$ Calculation across Standards and Eartips

Frequency (Hz)	Eartip Type	Standard	Sourced Kuduwave MPANL ($SPL_{actual\_ambient}$ App. B) (dB SPL)	KuduwaveMPANL $SPL_{recorded\_for\_correction\_calc}$ (dB SPL)	Combined Attenuation (dB) (App. A2/A3)	RETSPL/ ETSPL (dB SPL) (App. A1)	Calculated $MPANL_{Correction\ factor}$ (dB)
125	Foam	ANSI S3.1	60.0	63.0	31.0	28.0	**+4.0**
250	Foam	ANSI S3.1	58.7	61.7	37.7	17.5	**+6.5**
500	Foam	ANSI S3.1	59.8	62.8	43.8	9.5	**+9.5**
1000	Foam	ANSI S3.1	53.8	56.8	40.8	5.5	**+10.5**
2000	Foam	ANSI S3.1	52.1	55.1	38.1	11.5	**+5.5**
4000	Foam	ANSI S3.1	63.3	66.3	52.3	15.0	**–1.0**
8000	Foam	ANSI S3.1	59.8	62.8	45.8	15.5	**+1.5**
125	Silicone	ANSI S3.1	38.0	41.0	9.0	40.0	**–8.0**
250	Silicone	ANSI S3.1	31.0	34.0	10.0	25.5	**–1.5**
500	Silicone	ANSI S3.1	46.0	49.0	30.0	13.5	**+5.5**

1000	Silicone	ANSI S3.1	42.7	45.7	29.7	12.5	**+3.5**
2000	Silicone	ANSI S3.1	52.0	55.0	38.0	16.5	**+0.5**
4000	Silicone	ANSI S3.1	55.3	58.3	44.3	14.0	**0.0**
8000	Silicone	ANSI S3.1	41.0	44.0	27.0	19.5	**−2.5**
125	Foam	ISO 8253-1	51.0	54.0	31.0	28.0	**−5.0**
250	Foam	ISO 8253-1	50.7	53.7	37.7	17.5	**−1.5**
500	Foam	ISO 8253-1	51.8	54.8	43.8	9.5	**+1.5**
1000	Foam	ISO 8253-1	47.8	50.8	40.8	5.5	**+4.5**
2000	Foam	ISO 8253-1	46.1	49.1	38.1	11.5	**−0.5**
4000	Foam	ISO 8253-1	54.3	57.3	52.3	15.0	**−10.0**
8000	Foam	ISO 8253-1	60.8	63.8	45.8	15.5	**+2.5**
125	Silicone	ISO 8253-1	29.0	32.0	9.0	40.0	**−17.0**
250	Silicone	ISO 8253-1	23.0	26.0	10.0	25.5	**−9.5**
500	Silicone	ISO 8253-1	38.0	41.0	30.0	13.5	**−2.5**
1000	Silicone	ISO 8253-1	36.7	39.7	29.7	12.5	**−2.5**
2000	Silicone	ISO 8253-1	46.0	49.0	38.0	16.5	**−5.5**
4000	Silicone	ISO 8253-1	46.3	49.3	44.3	14.0	**−9.0**
8000	Silicone	ISO 8253-1	42.0	45.0	27.0	19.5	**−1.5**
125	Foam	SANS 10182	50.0	53.0	31.0	28.0	**−6.0**

250	Foam	SANS 10182	49.2	52.2	37.7	17.5	**–3.0**
500	Foam	SANS 10182	51.3	54.3	43.8	9.5	**+1.0**
1000	Foam	SANS 10182	47.3	50.3	40.8	5.5	**+4.0**
2000	Foam	SANS 10182	44.1	47.1	38.1	11.5	**–2.5**
4000	Foam	SANS 10182	54.3	57.3	52.3	15.0	**–10.0**
8000	Foam	SANS 10182	57.3	60.3	45.8	15.5	**–1.0**
125	Silicone	SANS 10182	28.0	31.0	9.0	40.0	**–18.0**
250	Silicone	SANS 10182	21.5	24.5	10.0	25.5	**–11.0**
500	Silicone	SANS 10182	37.5	40.5	30.0	13.5	**–3.0**
1000	Silicone	SANS 10182	36.2	39.2	29.7	12.5	**–3.0**
2000	Silicone	SANS 10182	44.0	47.0	38.0	16.5	**–7.5**
4000	Silicone	SANS 10182	46.3	49.3	44.3	14.0	**–9.0**
8000	Silicone	SANS 10182	38.5	41.5	27.0	19.5	**–5.0**

Note: Sourced Kuduwave MPANL ($SPL_{actual\_ambient}$) values are from Appendix B of this document.[1] Combined Attenuation from Appendix A2/A3. RETSPL/ETSPL from Appendix A1.

5.4. Significance and Interpretation of the $MPANL_{Correction\ Factor}$

The $MPANL_{Correction\ Factor}$ plays a crucial role in making the $SPHL_{in-ear}$ display clinically intuitive and directly comparable to the limits set by the chosen MPANL standard. Its primary function is to normalize the $SPHL_{in-ear}$ reading. When the

Kuduwave system's internally processed $SPL_{ambient\_recorded}$ (which is the $SPL_{actual\_ambient} + 3dB$) results in a $SPHL_{uncorrected}$ that, after subtraction of the $MPANL_{Correction\ Factor}$, yields an $SPHL_{in-ear}$ of 0 dB HL, it signifies a specific condition: the actual external ambient noise ($SPL_{actual\_ambient}$) is at the Kuduwave-specified MPANL [1] for testing down to 0 dB HL. This interpretation inherently includes the system's conservative $+ 3dB$ internal offset.

Therefore, the displayed $SPHL_{in-ear}$ can be interpreted as follows:

- A displayed $SPHL_{in-ear}$ of approximately **0 dB HL** indicates that the current ambient noise condition meets the Kuduwave-specified MPANL for the selected standard, eartip, and frequency, allowing for valid testing down to a 0 dB HL hearing level (when considering the system's internal conservative measures).
- **Positive** $SPHL_{in-ear}$ **values** (e.g., +5 dB HL) indicate that the in-ear noise exceeds this effective MPANL. Testing at very soft hearing levels (e.g., 0 dB HL) might be compromised by masking.
- **Negative** $SPHL_{in-ear}$ **values** (e.g., -10 dB HL) indicate that the in-ear noise is below this effective MPANL, meaning the environment is quieter than required by the standard for 0 dB HL testing, providing a greater margin of safety against masking.

This normalization simplifies clinical decision-making, as clinicians can directly relate the $SPHL_{in-ear}$ reading to the compliance status for the most stringent testing scenario (0 dB HL thresholds) according to the chosen standard.

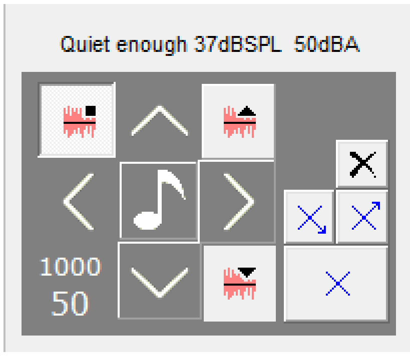
6. Interpreting Kuduwave's Real-Time Noise Data

The Kuduwave provides a multifaceted real-time display of the acoustic environment, offering clinicians immediate, actionable information to assess the suitability of testing conditions. Understanding these display elements is key to leveraging the $SPHL_{in-ear}$ metric effectively.

6.1. Real-Time Display: Visualizing the Acoustic Environment

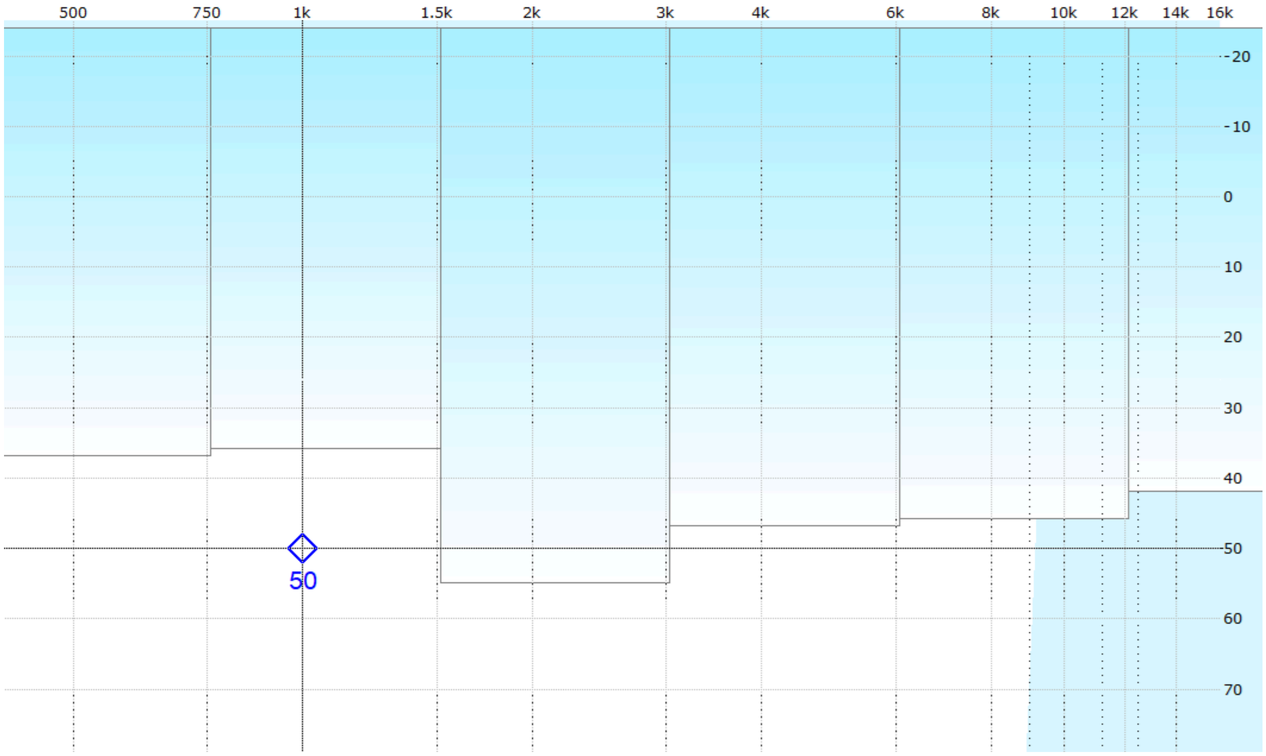
The Kuduwave interface presents several key noise metrics simultaneously [1]:

- $dB\ SPL$ **Monitoring:** For the specific octave band corresponding to the audiometric frequency currently being tested, the Kuduwave displays the actual measured ambient SPL ($SPL_{actual\_ambient}$) in real-time (e.g., "37dBSPL"). This gives a direct physical measure of the noise energy in that band.



- **dBA Monitoring:** An overall A-weighted sound level (dBA) is also displayed in real-time (e.g., "50dBA"). This is the actual measured A-weighted ambient sound level. The A-weighting scale approximates human loudness perception at lower levels and is commonly used for general environmental noise assessment, providing a single-figure indicator of the overall noise climate.

- **In-Ear dB HL Monitoring Bars ($SPHL_{in-ear}$):** Perhaps the most clinically intuitive display is the series of graphical bars, resembling a graphic equalizer, which dynamically represent the calculated $SPHL_{in-ear}$ for each standard audiometric frequency band (typically 125 Hz to 8000 Hz). These bars move up and down in real-time. The bars originate from the top of the display (representing lower dB HL values, e.g., -10 dB HL or -20 dB HL) and extend downwards as the in-ear noise level increases. This mirrors the conventional audiogram layout. The maximum downward excursion point of each bar at any moment indicates the current calculated $SPHL_{in-ear}$ (incorporating the $+\ 3dB$ offset and the $MPANL_{Correction\ Factor}$) in $dB\ HL$ for that frequency band.



6.2. Peak Noise Monitoring: Capturing Transient Sounds for Masking Relevance

Ambient noise often contains transient sounds or peaks, which can be short in duration but significant enough to mask audiometric stimuli. The Kuduwave employs a peak noise monitoring strategy, capturing the highest noise level occurring within very short (100 millisecond) windows.[1] This methodology is particularly sensitive to potentially masking sounds, as brief noise peaks can obscure short-duration pure-tone stimuli, which are typically used in audiometry. This ensures that the $SPHL_{in-ear}$ reflects not just average noise but also these critical transient events.

6.3. Noise Recording on Kuduwave Reports: Documenting Test Conditions

To ensure comprehensive documentation of the test conditions, the Kuduwave report includes an $SPHL_{in-ear}$ value for each frequency at which a hearing threshold was measured. This reported value is the average of the 100ms peak $SPHL_{in-ear}$ values recorded during a critical time window associated with each tone presentation. This window typically spans from the moment of tone presentation until the patient responds, up to a maximum of 2.5 seconds post-tone, or until the next tone is presented, whichever is shortest.[1] This method documents the effective peak noise conditions that were relevant to each individual threshold determination, providing valuable context for interpreting the audiogram.

7. Practical Application and Clinical Decision Making

The $SPHL_{in-ear}$ metric, calculated as detailed and normalized by the $MPANL_{Correction\ Factor}$ (Table 1), provides a powerful tool for clinicians. Its effective use involves understanding its calculation, interpretation, and the implications for audiometric testing.

7.1. Example Calculation of $SPHL_{in-ear}$

To illustrate the application of the 4-step calculation using the new $MPANL_{Correction\ Factor}$, consider an example using ANSI S3.1, Foam Eartips, at $250\ Hz$. Assume the external microphone measures an $SPL_{actual\_ambient}$ of $50\ dB\ SPL$ at $250\ Hz$.

1. **Internally Calculate Recorded Ambient SPL ($SPL_{ambient\_recorded}$):**

$$
\begin{aligned}
&SPL_{ambient\_recorded} \\
&= SPL_{actual\_ambient} + 3dB \\
&= 50dB + 3dB \\
&= 53dB\ SPL
\end{aligned}
$$

2. **Calculate In-Ear Noise SPL (SPL_{in-ear}):**
   From Appendix A, Table A2, Combined Attenuation for Foam eartips at $250\ Hz$ is 37.7 dB.

$$
\begin{aligned}
&SPHL_{in-ear} \\
&= SPL_{ambient\_recorded} - Attenuation_{earcup+eartip} \\
&= 53dB - 37.7dB \\
&= 15.3dB\ SPL
\end{aligned}
$$

3. Calculate Uncorrected Hearing Level (dBHLuncorrected):
   From Appendix A, Table A1, RETSPL for Foam eartips at $250\ Hz$ is $17.5\ dB\ SPL$.

$$
\begin{aligned}
& SPHL_{uncorrected} \\
& = SPL_{in-ear} - RETSPL \\
& = 15.3dB - 17.5dB \\
& =- 2.2dB\ HL
\end{aligned}
$$

4. Calculate Final $SPHL_{in-ear}$:

   From Table 1, the $MPANL_{Correction\ Factor}$ for ANSI S3.1, Foam eartips, $250\ Hz$ is $+\ 6.5\ dB$.

$$
\begin{aligned}
& SPL_{in-ear} \\
& = SPHL_{uncorrected} - MPANL_{Correction\ Factor} \\
& =- 2.2dB - (+\ 6.5dB) \\
& =- 8.7dB\ HL
\end{aligned}
$$

An $SPHL_{in-ear}$ of $-\ 8.7dB\ HL$ indicates that the current noise condition at $250\ Hz$ is well below the Kuduwave MPANL for ANSI S3.1 (when the system's conservative $+\ 3dB$ internal offset is factored in), suggesting a suitable environment for testing down to $0\ dB\ HL$ at this frequency.

7.2. Interpreting $SPHL_{in-ear}$ and Minimum Plateau Thresholds

The $SPHL_{in-ear}$ value is a key clinical tool for ensuring the validity of audiometric tests conducted outside of sound booths. Best practices for its interpretation and use include [1]:

1. **Prioritize $SPHL_{in-ear}$:** This is the most reliable real-time indicator of ambient noise influence on the test.
2. **Strive for Optimal Conditions:** For diagnostic testing aiming to establish true thresholds, significantly negative $SPHL_{in-ear}$ readings (e.g., -10 dB HL or lower) are desirable, as they indicate a very low risk of noise masking. For screening, ensure $SPHL_{in-ear}$ is well below the screening cut-off level.
3. **Ensure Proper Eartip Seal:** Achieving the specified attenuation (Appendix A, Tables A2 and A3) is critical. A poor seal compromises attenuation, leading to

higher actual in-ear noise than the system calculates. The Kuduwave includes a seal check feature for silicone tympanometer probe eartips.

4. **Select Correct Eartip in Software:** The software must be configured for the eartip type in use (foam or silicone), as this dictates the attenuation and RETSPL/ETSPL values used in calculations.
5. **Choose Quietest Environment Possible:** While Kuduwave is designed for non-booth use, selecting the quietest available location always improves test quality.
6. **Contextualize with MPANLs:** Be aware of the Kuduwave MPANLs (summarized in Appendix B) for the selected standard. An $SPHL_{in-ear}$ of $0\ dB\ HL$ implies the actual ambient noise is at this Kuduwave MPANL.
7. **Interpret In-Ear Noise Relative to Stimulus Level:** Ideally, the $SPHL_{in-ear}$ should be at least $10 - 15\ dB$ below the intended stimulus presentation level to minimize any risk of masking.
8. **Understand Limits of Threshold Determination:** The $SPHL_{in-ear}$ effectively sets a floor for the softest sound that can be reliably tested. A threshold cannot be confidently determined at or below the $SPHL_{in-ear}$.
9. **Utilize Kuduwave's Unique Threshold Annotations - Minimum Plateau Threshold:** GeoAxon has introduced an important audiogram annotation: the "up arrow" (↑) symbol, used in conjunction with standard audiometric symbols e.g:

This symbol denotes a Minimum Plateau Threshold. It indicates that the marked threshold is the softest level at which the patient responded, but further testing at softer levels was not possible or deemed unnecessary. This limitation could be due to several reasons [1]:

- The $SPHL_{in-ear}$ being too high to permit testing at the next $5\ dB$ decrement without significant risk of masking.
- A clinical decision in a screening protocol where testing below a defined pass

level (e.g., $25\ dB\ HL$) is not required.

The Minimum Plateau Threshold annotation is the inverse of the traditional "no response" down arrow (↓) and provides crucial context about the limitations influencing the obtained threshold. Its use is a significant contribution to accurate audiometric record-keeping, clearly distinguishing a true, unconstrained threshold from one that is limited by the test environment, protocol constraints, or the intrinsic hearing limits of the patient at very soft presentation levels.

10. **Troubleshoot High In-Ear Noise Readings:** If $SPHL_{in-ear}$ is consistently high, re-instruct the patient on remaining still and quiet, or consider moving to a quieter location if feasible.

7.3. Quick Lookup: Estimating $SPL_{actual\_ambient}$ from $SPHL_{in-ear}$

While $SPHL_{in-ear}$ is the primary clinical metric, users may sometimes wish to estimate the actual external ambient SPL ($SPL_{actual\_ambient}$) that corresponds to a given $SPHL_{in-ear}$ reading. This conversion can be useful for relating Kuduwave readings to external sound level meter measurements or for a deeper understanding of the environmental acoustics. The relationship, reversing the 4-step $SPHL_{in-ear}$ calculation, is:

$$SPL_{actual\_ambient} = SPHL_{in-ear} + MPANL_{Correction\ Factor} + RETSPL/ETSPL + Attenuation_{earcup+eartip} - 3dB$$

The "Value to Add" to a given $SPHL_{in-ear}$ reading to estimate the $SPL_{actual\_ambient}$ is therefore:

$$MPANL_{Correction\ Factor} + RETSPL/ETSPL + Attenuation_{earcup+eartip} - 3dB$$

Table 2 provides these "Value to Add" figures for ANSI S3.1, ISO 8253-1, and SANS 10182 standards, for both foam and silicone eartips. These values have been calculated using the new $MPANL_{Correction\ Factor}$ from Table 1 and the relevant transducer parameters from Appendix A. This table provides a practical tool for users to quickly understand the actual external noise level that corresponds to a given $SPHL_{in-ear}$ reading, taking into account all internal Kuduwave adjustments and the selected standard.

Table 2: Value to Add to Final $SPHL_{in-ear}$ to Estimate $SPL_{actual\_ambient}$ ($dB\ SPL$)

Frequency (Hz)	Eartip Type	Standard	MPANL Corr. Factor (Table 1) (dB)	RETSPL/ ETSPL ($dB\ SPL$) (App. A1)	Combined Attenuation (dB) (App. A2/A3)	Value to Add (dB) to $SPHL_{in-ear}$ to get $SPL_{actual\_ambient}$
125	Foam	ANSI S3.1	+4.0	28.0	31.0	**60.0**
250	Foam	ANSI S3.1	+6.5	17.5	37.7	**58.7**
500	Foam	ANSI S3.1	+9.5	9.5	43.8	**59.8**
1000	Foam	ANSI S3.1	+10.5	5.5	40.8	**53.8**
2000	Foam	ANSI S3.1	+5.5	11.5	38.1	**52.1**
4000	Foam	ANSI S3.1	-1.0	15.0	52.3	**63.3**
8000	Foam	ANSI S3.1	+1.5	15.5	45.8	**59.8**
125	Silicone	ANSI S3.1	-8.0	40.0	9.0	**38.0**
250	Silicone	ANSI S3.1	-1.5	25.5	10.0	**31.0**
500	Silicone	ANSI S3.1	+5.5	13.5	30.0	**46.0**
1000	Silicone	ANSI S3.1	+3.5	12.5	29.7	**42.7**
2000	Silicone	ANSI S3.1	+0.5	16.5	38.0	**52.0**

4000	Silicone	ANSI S3.1	0.0	14.0	44.3	**55.3**
8000	Silicone	ANSI S3.1	-2.5	19.5	27.0	**41.0**
125	Foam	ISO 8253-1	-5.0	28.0	31.0	**51.0**
250	Foam	ISO 8253-1	-1.5	17.5	37.7	**50.7**
500	Foam	ISO 8253-1	+1.5	9.5	43.8	**51.8**
1000	Foam	ISO 8253-1	+4.5	5.5	40.8	**47.8**
2000	Foam	ISO 8253-1	-0.5	11.5	38.1	**46.1**
4000	Foam	ISO 8253-1	-10.0	15.0	52.3	**54.3**
8000	Foam	ISO 8253-1	+2.5	15.5	45.8	**60.8**
125	Silicone	ISO 8253-1	-17.0	40.0	9.0	**29.0**
250	Silicone	ISO 8253-1	-9.5	25.5	10.0	**23.0**
500	Silicone	ISO 8253-1	-2.5	13.5	30.0	**38.0**
1000	Silicone	ISO 8253-1	-2.5	12.5	29.7	**36.7**
2000	Silicone	ISO 8253-1	-5.5	16.5	38.0	**46.0**
4000	Silicone	ISO 8253-1	-9.0	14.0	44.3	**46.3**
8000	Silicone	ISO 8253-1	-1.5	19.5	27.0	**42.0**
125	Foam	SANS 10182	-6.0	28.0	31.0	**50.0**
250	Foam	SANS 10182	-3.0	17.5	37.7	**49.2**
500	Foam	SANS 10182	+1.0	9.5	43.8	**51.3**

1000	Foam	SANS 10182	+4.0	5.5	40.8	**47.3**
2000	Foam	SANS 10182	-2.5	11.5	38.1	**44.1**
4000	Foam	SANS 10182	-10.0	15.0	52.3	**54.3**
8000	Foam	SANS 10182	-1.0	15.5	45.8	**57.3**
125	Silicone	SANS 10182	-18.0	40.0	9.0	**28.0**
250	Silicone	SANS 10182	-11.0	25.5	10.0	**21.5**
500	Silicone	SANS 10182	-3.0	13.5	30.0	**37.5**
1000	Silicone	SANS 10182	-3.0	12.5	29.7	**36.2**
2000	Silicone	SANS 10182	-7.5	16.5	38.0	**44.0**
4000	Silicone	SANS 10182	-9.0	14.0	44.3	**46.3**
8000	Silicone	SANS 10182	-5.0	19.5	27.0	**38.5**

Note: The MPANL Correction Factors from Table 1. RETSPL/ETSPL from Appendix A1. Combined Attenuation from Appendix A2/A3.

8. Conclusion: Enhanced Precision and Confidence in Boothless Audiometry with Kuduwave

The Kuduwave audiometer, with its refined ambient noise monitoring system and the detailed analytical framework presented in this white paper, significantly advances the capabilities and reliability of boothless audiometry. The 4-step calculation for the $SPHL_{in-ear}$ metric, which incorporates a conservative $+\ 3dB\ SPL$ internal recording offset and newly defined, standard-specific $MPANL_{Correction\ Factor}$s, provides clinicians with precise and intuitively interpretable measures of in-ear acoustic conditions.

A key methodological enhancement detailed herein is the sourcing of Kuduwave-specific Maximum Permissible Ambient Noise Levels (MPANLs) from a dedicated GeoAxon guide, "Establishing Maximum Permissible Ambient Noise Levels for the Kuduwave Audiometer: A Guide for Clinical, Research, and Proposed Unified Global Applications".[1] This standardized approach to MPANLs forms a robust foundation for the calculation of the MPANLCorrection Factors (presented in Table 1) for ANSI S3.1, ISO 8253-1, and SANS 10182 standards, covering both foam and silicone eartip configurations. This separation of MPANL establishment from the $SPHL_{in-ear}$ calculation logic creates a more transparent, maintainable, and scientifically grounded framework for the Kuduwave's noise management system.

The normalization of the $SPHL_{in-ear}$ display to the selected MPANL standard, achieved through these correction factors, simplifies clinical interpretation and substantially boosts diagnostic confidence when testing outside of conventional sound booths. Furthermore, the introduction and application of the "Minimum Plateau Threshold" annotation enhance the accuracy and contextual richness of audiometric reporting, particularly in challenging acoustic environments or when patient limitations are encountered.[1]

The detailed methodologies for deriving $SPHL_{in-ear}$, the tools for estimating actual ambient SPL from the displayed $SPHL_{in-ear}$ (Table 2), and the careful application of eartip-specific transducer parameters (Appendix A) underscore GeoAxon's commitment to precision and accuracy in audiometric assessment. By providing these sophisticated tools and a clear, scientifically sound basis for their application, the Kuduwave system sets a new benchmark for precision and reliability in boothless audiometry. This empowers hearing healthcare professionals to confidently extend high-quality audiometric assessments to diverse populations and settings, ultimately improving access to vital hearing care services.

9. References

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Appendix A: Kuduwave Transducer Parameters

Table A1: Kuduwave RETSPLs (Foam Eartip) and ETSPLs (Silicone Eartip)

(Values in $dB\ SPL$ re $20\ \mu Pa$)

(Sources: Kuduwave Technical Specifications 1; ISO 389-2 1 for foam eartip principles; Ramatshoma et al., 2021 [1, 1] for silicone eartip ETSPLs)

Frequency (Hz)	RETSPL (Foam Eartip)	ETSPL (Silicone Eartip)
125	28.0	40.0
250	17.5	25.5
500	9.5	13.5
750	6.0	10.5

1000	5.5	12.5
1500	9.5	11.5
2000	11.5	16.5
3000	13.0	17.0
4000	15.0	14.0
6000	16.0	15.0
8000	15.5	19.5

Table A2: Kuduwave Combined Ear-cup and Foam Eartip Attenuation (dB)
(Sources: Kuduwave Technical Specifications 1; Swanepoel et al., 2015 1)

Frequency (Hz)	Attenuation (dB)
125	31.0
250	37.7
500	43.8
750	N/A*
1000	40.8
1500	N/A*
2000	38.1
3000	49.2
4000	52.3

6000	48.8
8000	45.8

*N/A: Values for 750 Hz and 1500 Hz are not explicitly listed in Kuduwave Technical Specifications for foam eartip attenuation. The Kuduwave system utilizes its complete internal dataset. Values for 3000 Hz and 6000 Hz are from Swanepoel et al. (2015).[1]

Table A3: Kuduwave Combined Ear-cup and Silicone (Immittance) Eartip Attenuation (dB)
(Sources: Kuduwave Technical Specifications 1; Ramatshoma et al., 2021 [1, 1])

Frequency (Hz)	Attenuation (dB)
125	9.0
250	10.0
500	30.0
750	33.3
1000	29.7
1500	33.0
2000	38.0
3000	46.0
4000	44.3
6000	35.7
8000	27.0

Appendix B: Sourced Kuduwave Maximum Permissible Ambient Noise

Levels ($SPL_{actual\_ambient}$) for Diagnostic Testing to $0\ dB\ HL$

The following tables provide Kuduwave Maximum Permissible Ambient Noise Levels (MPANLs), expressed as $SPL_{actual\_ambient}$ in $dB\ SPL$, for diagnostic testing to $0\ dB\ HL$. These values are sourced directly from the GeoAxon white paper: "Establishing Maximum Permissible Ambient Noise Levels for the Kuduwave Audiometer: A Guide for Clinical, Research, and Proposed Unified Global Applications".[1] These MPANLs are used in Section 5 of the current document to derive the MPANLCorrection Factors.

Table B1: Sourced Kuduwave MPANLs ($SPL_{actual\_ambient}$, $0\ dB\ HL$) for ANSI S3.1

Frequency (Hz)	Eartip Type	Kuduwave MPANL (dB $SPL_{actual\_ambient}$)
125	Foam	60.0
250	Foam	58.7
500	Foam	59.8
1000	Foam	53.8
2000	Foam	52.1
4000	Foam	63.3
8000	Foam	59.8
125	Silicone	38.0
250	Silicone	31.0
500	Silicone	46.0
1000	Silicone	42.7
2000	Silicone	52.0

4000	Silicone	55.3
8000	Silicone	41.0

Table B2: Sourced Kuduwave MPANLs ($SPL_{actual\_ambient}$, 0dB HL) for ISO 8253-1

Frequency (Hz)	Eartip Type	Kuduwave MPANL (dB $SPL_{actual\_ambient}$)
125	Foam	51.0
250	Foam	50.7
500	Foam	51.8
1000	Foam	47.8
2000	Foam	46.1
4000	Foam	54.3
8000	Foam	60.8
125	Silicone	29.0
250	Silicone	23.0
500	Silicone	38.0
1000	Silicone	36.7
2000	Silicone	46.0
4000	Silicone	46.3
8000	Silicone	42.0

Table B3: Sourced Kuduwave MPANLs ($SPL_{actual\_ambient}$, 0dB HL) for SANS 10182

Frequency (Hz)	Eartip Type	Kuduwave MPANL (dB $SPL_{actual\_ambient}$)
125	Foam	50.0
250	Foam	49.2
500	Foam	51.3
1000	Foam	47.3
2000	Foam	44.1
4000	Foam	54.3
8000	Foam	57.3
125	Silicone	28.0
250	Silicone	21.5
500	Silicone	37.5
1000	Silicone	36.2
2000	Silicone	44.0
4000	Silicone	46.3
8000	Silicone	38.5