Establishing Maximum Permissible Ambient Noise Levels for the Kuduwave Audiometer: A Guide for Clinical, Research, and Proposed Unified Global Applications

Authors: Dr HL (Dirk) Koekemoer, Tiehan Nel
Affiliation: GeoAxon
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Abstract

Background: The accuracy of audiometric testing is critically dependent on a controlled acoustic environment to prevent ambient noise from masking test stimuli. Traditional sound-treated booths, while effective, present limitations in cost, portability, and accessibility. The Kuduwave audiometer is an innovative, portable diagnostic system designed for accurate hearing assessments outside of such booths, primarily due to its advanced passive sound attenuation.
Objective: This white paper defines and calculates Kuduwave-specific Maximum Permissible Ambient Noise Levels (MPANLs) according to ANSI S3.1-1999 (R2013), BS EN ISO 8253-1:2010, and SANS 10182:2006 for air and bone conduction audiometry. The Kuduwave's unique dual passive attenuation system necessitates these specific calculations, a practice supported by the framework of audiometric standards. For air conduction, it considers minimum test thresholds (0 dB HL, 15 dB HL, 25 dB HL). For bone conduction, MPANLs are presented for 0 dB HL, as this is the standard clinical practice. Calculations consider different eartips (foam, silicone). Critically, this expanded paper proposes a novel, unified global MPANL standard specifically for the Kuduwave audiometer, synthesizing the most protective aspects of existing

international standards using a common baseline for both air and bone conduction calculations within this unified framework.
Methods: Kuduwave-specific MPANLs are calculated by adding the device's empirically determined combined sound attenuation (earcup + eartip) to the "ears not covered" or equivalent unoccluded baseline MPANLs from each standard. Adjustments for 15 dB HL and 25 dB HL are made for air conduction testing. The proposed unified standard derives a single consolidated, most stringent "ears not covered" baseline from the three aforementioned standards; Kuduwave's attenuation is then applied to this common baseline to determine unified MPANLs for both air conduction (0, 15, and 25 dB HL) and bone conduction (0 dB HL), maintaining distinctions for eartip type.
Results: The Kuduwave audiometer permits reliable hearing assessments in ambient noise levels considerably higher than those acceptable for unoccluded or conventional supra-aural earphone testing. Distinct MPANL tables are presented for each standard and eartip. The proposed unified Kuduwave MPANLs offer a single, globally applicable set of values, aiming for maximum test validity by adopting a conservative common baseline.
Conclusion: The established Kuduwave-specific MPANLs and the newly proposed unified global MPANL standard provide robust, evidence-based guidance for clinicians and researchers. This work supports the Kuduwave's role in increasing access to reliable hearing healthcare in diverse settings. The unified standard, in particular, offers a path towards global harmonization and simplified, consistent application of the Kuduwave, potentially serving as a model for other advanced audiometric technologies.

1. Executive Summary

This white paper defines and calculates the Maximum Permissible Ambient Noise Levels (MPANLs) for the GeoAxon Kuduwave audiometer. These calculations are performed in accordance with three key standards: ANSI S3.1-1999 (R2013), BS EN ISO 8253-1:2010, and SANS 10182:2006. The Kuduwave's unique dual passive attenuation system necessitates these specific calculations, as generic MPANLs provided in standards for common earphones do not apply. The MPANLs are determined for audiometric testing (both air and bone conduction). For air conduction, MPANLs are provided for minimum hearing threshold levels of $0\ dB\ HL$, 15 dB HL, and 25 dB HL. For bone conduction, MPANLs are provided for testing to $0\ dB\ HL$, reflecting standard clinical practice. These calculations consider the distinct sound attenuation characteristics of the Kuduwave when used with both foam eartips and Silicone (Tympanometry Probe Tip) eartips. [1] A comparison with previously published MPANLs by Swanepoel et al. (2015) is also provided. [1] Furthermore, this paper proposes a framework for a unified global MPANL standard for the Kuduwave, synthesizing the strengths of existing international guidelines and using a common, conservatively derived baseline for both air and bone conduction MPANLs within this unified proposal to further enhance its applicability and consistency in diverse global settings.

The Kuduwave audiometer's significant sound attenuation capabilities are central to its ability to perform accurate audiometry in environments outside of traditional sound-treated booths. By quantifying the MPANLs based on existing standards and proposing a unified standard, this document provides clear, evidence-based guidelines for clinicians and researchers. The findings underscore the Kuduwave's capacity to facilitate reliable hearing assessments in a variety of settings, including occupational health, schools, and remote clinics, thereby potentially increasing access to essential hearing healthcare services. This paper is structured to be clearly understandable for healthcare practitioners such as nurses and doctors, while also offering the technical depth required by audiologists and researchers.

2. Introduction: The Critical Role of Ambient Noise Control in Audiometry

The accurate assessment of hearing thresholds is a cornerstone of audiological practice, with particular importance in occupational health surveillance programs where early detection of noise-induced hearing loss is paramount. [1] However, the validity of any audiometric test is fundamentally dependent on a controlled acoustic environment. Ambient noise, if not adequately managed, poses a significant threat to test accuracy by masking the pure-tone stimuli presented to the patient. This masking effect can lead to erroneously elevated hearing thresholds, potentially resulting in misdiagnosis, inappropriate clinical management, or incorrect fitness-for-duty assessments. [1]

Traditionally, the challenge of ambient noise has been addressed through the use of sound-treated audiometric booths. While effective when properly specified and maintained, these booths present considerable limitations, including high costs, lack of portability, and the need for regular certification, which can restrict accessibility to hearing testing, especially in resource-limited settings or for on-site industrial screening. [1] Furthermore, studies have indicated that even installed booths may not consistently meet the required MPANLs, particularly for low-frequency noise or when transient noises are present. [1]

The Kuduwave audiometer, developed by GeoAxon, represents an innovative approach to these challenges. It is engineered as a portable, diagnostic audiometer designed to deliver accurate hearing assessments outside the confines of a traditional sound booth. [1] A key design feature enabling this capability is its advanced passive sound attenuation system, which significantly reduces the influence of ambient noise at the patient's ear. This unique "double passive attenuation" (earcup plus insert eartip) means that generic MPANL values found in standards for typical earphones are not applicable; instead, device-specific MPANLs must be determined for the Kuduwave.

The objective of this white paper is to define and present these device-specific MPANLs for the Kuduwave audiometer for both air conduction (AC) and bone conduction (BC) testing. These MPANLs are calculated based on the device's unique sound attenuation characteristics when using both foam eartips and Silicone (Tympanometry Probe Tip) eartips. For AC, the calculations will address various minimum hearing level testing scenarios ($0\ dB\ HL$, 15 dB HL, and 25 dB HL). For BC, calculations will focus on testing to $0\ dB\ HL$. These will be performed in accordance with three internationally recognized standards: ANSI S3.1-1999 (R2013), BS EN ISO 8253-1:2010, and SANS 10182:2006. [1] By establishing these device-specific MPANLs, this paper aims to provide clinicians and researchers with the necessary information to confidently utilize the Kuduwave for reliable audiometric testing in a broader range of environments. This supports a critical shift towards more accessible and validated boothless audiometry, a need highlighted in contemporary audiology literature. [1]

3. Understanding MPANLs

MPANLs are defined as the highest sound pressure levels (SPL) of ambient noise, typically specified in octave or one-third octave frequency bands, that are permitted in a test environment without significantly affecting the accuracy of audiometric thresholds being measured. [1] Essentially, if ambient noise exceeds these levels, there is a risk that the noise will mask the test tones, making them harder for the patient to hear, thus leading to an overestimation of their hearing thresholds, which might possibly result in an incorrect diagnosis. This is why the establishment of MPANLs is crucial for ensuring the validity and reliability of audiometric tests. All major standards governing audiometric testing provide specifications for these levels, recognizing that an uncontrolled acoustic environment is a primary source of error. [1]

Overview of Key Standards and the "Ears Not Covered" Principle:

- **ANSI S3.1-1999 (R2013):** This American National Standard specifies MPANLs for audiometric test rooms designed to produce negligible masking (defined as ≤2 dB threshold shift) when testing at reference equivalent threshold levels ($0\ dB\ HL$). It provides MPANLs in both octave and one-third octave bands for two primary conditions: "ears covered" (e.g., with supra-aural or insert earphones) and "ears not covered." [1]
- **BS EN ISO 8253-1:2010:** This international standard details procedures for pure-tone air and bone conduction threshold audiometry. It specifies MPANLs, denoted as LS,max, in one-third octave bands, necessary to avoid masking of test tones when measuring thresholds down to $0\ dB\ HL$. [1]
- **SANS 10182:2006:** This South African National Standard outlines procedures for the measurement and assessment of acoustic environments for audiometric tests. It specifies MPANLs in octave bands for various audiometric procedures, including air conduction and bone conduction, with values typically provided for testing down to a $0\ dB\ HL$ minimum. [1]

A fundamental concept for calculating device-specific MPANLs, such as those for the Kuduwave, is the "Ears Not Covered" baseline. The MPANLs specified in standards for "ears not covered" conditions represent the maximum ambient noise allowed in the environment before considering any sound attenuation provided by an earphone or headset. [1] This baseline is critical because the specific attenuation of the Kuduwave headset is then added to this "ears not covered" MPANL to determine the actual, higher ambient noise levels permissible when using the Kuduwave. This approach is more accurate than relying on generic "ears covered" MPANLs from standards, which assume different, often less effective, earphone types. Indeed, audiometric standards like ISO 8253-1 and SANS 10182 provide the framework that allows manufacturers to determine specific MPANLs for their headsets if the attenuation characteristics are unique and not covered by standard earphone data within the standard itself. This is precisely the case for the Kuduwave's dual attenuation system, making the calculation of its own MPANLs essential.

Adjusting MPANLs for Different Minimum Test Thresholds:

The MPANLs provided in standards are typically for the most stringent condition: measuring hearing thresholds down to $0\ dB\ HL$. However, for certain applications, such as screening audiometry (typically air conduction), the goal might be to identify hearing loss exceeding a higher threshold, for example, $15\ dB\ HL$ or $25\ dB\ HL$. In such cases, the permissible ambient noise levels can be higher. The principle, consistently supported across standards, is that the MPANL can be increased by the same amount as the increase in the minimum hearing level being tested. [1] For instance, ANSI S3.1-1999 (R2013) states that MPANLs for testing above 0 dB are derived by arithmetically adding the amount above 0 dB to the baseline MPANLs. BS EN ISO 8253-1:2010 and ISO 6189:1983 follow the same principle. [1] This consistent approach across standards provides a robust and universally accepted method for calculating MPANLs for air conduction testing scenarios where the minimum target threshold is above $0\ dB\ HL$, simplifying a key aspect of the calculations performed in this white paper and forming a strong justification for its inclusion in any proposed unified standard for air conduction. For bone conduction, testing is typically performed to a $0\ dB\ HL$ reference.

4. Kuduwave Technology: Advanced Attenuation for Boothless Audiometry

The Kuduwave audiometer's design is centered on enabling accurate audiometric assessments in environments where traditional sound booths are unavailable or impractical. A cornerstone of this capability is its sophisticated passive noise attenuation system, marketed as *Ambi-Dome* technology. This system integrates the effects of circumaural earcups with occluding insert eartips to create a high degree of isolation for the patient's ear from external ambient noise. [1] This "double passive attenuation" is a key differentiator.

The effectiveness of this attenuation is critical, as it directly determines the level of ambient noise that can be tolerated without compromising test validity. The Kuduwave system can be used with two primary types of eartips: foam eartips and Silicone (Tympanometry Probe Tip) eartips. [1] These eartips exhibit different acoustic coupling and, consequently, different sound attenuation characteristics, especially at lower frequencies. It is therefore essential to consider them separately when determining MPANLs. The substantial difference in attenuation performance between these eartip types, particularly the superior low-frequency attenuation of foam eartips, necessitates that any credible MPANL standard, whether existing or a newly proposed unified one, must provide distinct values for each. A single MPANL value would inevitably be either overly restrictive for foam eartips or insufficiently protective (and thus unsafe) when silicone eartips are used.

Kuduwave Combined Sound Attenuation Data:

The combined sound attenuation values for the Kuduwave headset ($\alpha_{earcup+eartip}$) are empirically determined and are presented below. These values, fundamental to all subsequent Kuduwave-specific MPANL calculations, represent the reduction in sound pressure level from the external environment to the ear canal.

Table 1: Kuduwave Combined Sound Attenuation - Foam Eartips (dB)

Frequency (Hz)	Attenuation (dB)
125	31.0
250	37.7
500	43.8
1000	40.8
2000	38.1
4000	52.3
8000	45.8

Source: Kuduwave Pro TMP Datasheet; Consistent with Swanepoel et al., 2015 [1]

Table 2: Kuduwave Combined Sound Attenuation - Silicone (Tympanometry Probe Tip) eartips (dB)

Frequency (Hz)	Attenuation (dB)
125	9.0

250	10.0
500	30.0
1000	29.7
2000	38.0
4000	44.3
8000	27.0

Source: Kuduwave Pro TMP Datasheet; Identical to Ramatshoma et al., 2021 [1]

A comparison of the data in Table 1 and Table 2 reveals that the choice of eartip significantly impacts the achieved sound attenuation. Foam eartips generally provide considerably higher attenuation than Silicone (Tympanometry Probe Tip) eartips, particularly at lower frequencies e.g., at $125\ Hz$, foam eartips offer $31.0\ dB$ attenuation compared to $9.0\ dB$ for Silicone (Tympanometry Probe Tip) eartips. [1] This difference of over $20\ dB$ at some frequencies will directly translate into different MPANLs for the Kuduwave depending on the eartip used. [1] The attenuation levels achieved by the Kuduwave system, especially with foam eartips, are substantial and can exceed those of typical transportable sound-treated booths, particularly at challenging low frequencies. [1] This high level of passive attenuation is a key factor that enables the Kuduwave to be used effectively in environments with ambient noise levels that would render testing with standard supra-aural headphones or unoccluded ears invalid.

5. Methodology for Calculating Kuduwave Air Conduction (AC) MPANLs

The calculation of MPANLs specific to the Kuduwave audiometer, with its unique dual passive attenuation system, relies on a core principle that combines standardized baseline noise limits with the device's measured sound attenuation capabilities. This methodology is employed precisely because generic MPANL values are insufficient for such specialized equipment, and it aligns with the framework provided by audiometric standards for determining device-specific MPANLs. This ensures that the derived Kuduwave MPANLs are both scientifically sound and directly applicable to real-world testing scenarios. [1]

Core Principle for $0\ dB\ HL$ Testing:

The fundamental formula used to calculate the Kuduwave's MPANL for accurate audiometric testing down to a $0\ dB\ HL$ minimum threshold is:

$$MPANL_{Kuduwave\_0\ dB\ HL}(dB\ SPL)$$

$$= MPANL_{Standard\_EarsNotCovered\_0\ dB\ HL}(dB\ SPL)\ +\ \alpha_{earcup+eartip}$$

Where:

- $MPANL_{Kuduwave\_0dBHL}$ is the maximum permissible external ambient sound pressure level (in $dB\ SPL$, at a specific octave band frequency) in which the Kuduwave can accurately test hearing down to $0\ dB\ HL$.
- $MPANL_{Standard\_EarsNotCovered\_0\ dB\ HL}$ is the maximum ambient SPL specified by the respective standard (ANSI S3.1, ISO 8253-1, or SANS 10182) for testing with ears unoccluded, or an equivalent condition, when the minimum test threshold is $0\ dB\ HL$. [1]
- $\alpha_{earcup+eartip}$ is the combined sound attenuation (in dB, at the corresponding frequency) provided by the Kuduwave earcup and the specific eartip in use. [1]

This approach is consistent with methodologies described in published research and is robust because it starts with a standardized, worst-case baseline (ears not covered) and then incorporates the empirically measured, device-specific attenuation of the Kuduwave. [1]

Calculation for $15\ dB\ HL$ and $25\ dB\ HL$ Minimum Test Thresholds (for Air Conduction):

Once the $MPANL_{Kuduwave\_AC\_0\ dB\ HL}$ is established, the MPANLs for air conduction testing to higher minimum thresholds are determined by:

$$MPANL_{Kuduwave\_AC\_XdB\ HL} = MPANL_{Kuduwave\_AC\_0\ dB\ HL} + X\ dB$$

Where X is the minimum hearing level to be tested (i.e., $15\ dB$ or $25\ dB$). This principle is explicitly supported by the referenced standards for air conduction. [1]

Contextual Note on Kuduwave's Internal Noise Assessment:

It is important to distinguish the external MPANLs calculated in this white paper from the Kuduwave's internal, real-time noise assessment system. The Kuduwave software displays a metric called "Noise in ear canal (External mic) dB HL" ($SPHL_{in-ear}$). The calculation of this $SPHL_{in-ear}$ value involves an internal $+\ 3\ dB\ SPL$ offset applied to the actually measured external ambient SPL ($SPL_{actual\_ambient}$). [1] This internal $+\ 3\ dB$ offset is a conservative measure. It means that when the Kuduwave's $SPHL_{in-ear}$ display indicates that the test environment is quiet enough (e.g., $SPHL_{in-ear} \leq 0\ dB$ for a $0\ dB\ HL$ test target, relative to the selected standard), the actual external ambient noise is comfortably within the external MPANLs calculated in this white paper. [1] This built-in conservatism provides an inherent safety margin, simplifying practical adherence to any MPANL, including a future unified one, as the device itself guides users towards compliance more stringently than the external limits require.

6. Kuduwave AC MPANLs for ANSI S3.1-1999 (R2013)

ANSI S3.1-1999 (R2013) is the American National Standard that specifies MPANLs for Audiometric Test Rooms. It is a comprehensive standard widely used in North America and referenced internationally. To calculate Kuduwave-specific AC MPANLs based on ANSI S3.1, the "Ears Not Covered" MPANLs for 0 dB HL testing are taken from Table 3 of the standard (Octave Band data for the 125 Hz to 8000 Hz test frequency range). [1]

The baseline MPANLs from ANSI S3.1-1999 Table 3 (Ears Not Covered, Octave Bands, 125 Hz to 8000 Hz test range, $0\ dB\ HL$) are presented in Table 3a. [1]

Table 3a: ANSI S3.1-1999 Table 3 Baseline MPANLs (Ears Not Covered, Octave Bands, 125-8000Hz, $0\ dB\ HL$)

Source: 1

Frequency (Hz)	MPANL (dB SPL)
125	29.0
250	21.0
500	16.0
1000	13.0
2000	14.0
4000	11.0
8000	14.0

These baseline values are added to the Kuduwave's attenuation values (from Table 1 for foam eartips and Table 2 for Silicone (Tympanometry Probe Tip) eartips) to derive the MPANLKuduwave_AC_0 dB HL. Subsequently, 15 dB and 25 dB are added to these 0 dB HL MPANLs to determine the levels for testing to minimums of 15 dB HL and 25 dB HL, respectively, as per ANSI S3.1, Section 5. [1]

Table 3: Calculated Kuduwave AC MPANLs (dB SPL, Octave Bands) based on ANSI S3.1-1999 (Ears Not Covered, $125 - 8000Hz$ Data for $0\ dB\ HL$ Baseline)

Frequency (Hz)	Eartip Type	ANSI S3.1 MPANL (Ears Not Covered, $0\ dB\ HL$) (dB SPL)	Kuduwave Combined Attenuation (dB)	Kuduwave AC MPANL ($0\ dB\ HL$) (dB SPL)	Kuduwave AC MPANL ($15\ dB\ HL$) (dB SPL)	Kuduwave AC MPANL ($25dB\ HL$) (dB SPL)
125	Foam	29.0	31.0	**60.0**	75.0	85.0
250	Foam	21.0	37.7	**58.7**	73.7	83.7
500	Foam	16.0	43.8	**59.8**	74.8	84.8

1000	Foam	13.0	40.8	**53.8**	68.8	78.8
2000	Foam	14.0	38.1	**52.1**	67.1	77.1
4000	Foam	11.0	52.3	**63.3**	78.3	88.3
8000	Foam	14.0	45.8	**59.8**	74.8	84.8
125	Silicone	29.0	9.0	**38.0**	53.0	63.0
250	Silicone	21.0	10.0	**31.0**	46.0	56.0
500	Silicone	16.0	30.0	**46.0**	61.0	71.0
1000	Silicone	13.0	29.7	**42.7**	57.7	67.7
2000	Silicone	14.0	38.0	**52.0**	67.0	77.0
4000	Silicone	11.0	44.3	**55.3**	70.3	80.3
8000	Silicone	14.0	27.0	**41.0**	56.0	66.0

Derived from [1].

The Kuduwave Pro TMP Datasheet [1] also presents MPANLs calculated against ANSI S3.1. The values derived in Table 3 of this white paper, using the direct $MPANL_{Standard\_EarsNotCovered} + \alpha_{earcup+eartip}$ methodology, are systematically derived from the ANSI S3.1 baseline. These values are identical to those presented in the Kuduwave Pro TMP Datasheet for Kuduwave insert earphones testing to a minimum threshold of $0\ dB\ HL$ (test frequency range $125 - 8000\ Hz$). [1] ANSI S3.1 is a highly detailed standard, and aligning Kuduwave's MPANLs with its core principles-such as ensuring negligible masking and accommodating specific test frequency ranges-enhances the technical credibility of these values for researchers and clinicians.

7. Kuduwave AC MPANLs for BS EN ISO 8253-1:2010

BS EN ISO 8253-1:2010 is a key international standard for audiometric test methods, encompassing pure-tone air and bone conduction audiometry. To establish Kuduwave-specific AC MPANLs based on this standard, baseline "Ears Not Covered" MPANLs for $0\ dB\ HL$ testing are required. ISO 8253-1 Table 4 provides "Maximum permissible ambient sound pressure levels in one-third-octave bands, for bone conduction audiometry for hearing threshold level measurements down to $0\ dB$". Bone conduction audiometry serves as an appropriate "ears not covered" equivalent. [1]

A methodological consideration arises because ISO 8253-1 Table 4 specifies MPANLs in one-third octave bands, while the Kuduwave's combined attenuation data (Tables 1 and 2 of this white paper) is primarily available in octave bands. For these calculations, the one-third octave MPANL from ISO 8253-1 Table 4 corresponding to the center frequency of each octave band will be used as the baseline. The Kuduwave's octave band attenuation for that same center frequency will then be added. This is a common and defensible approach when combining data of differing bandwidths if full one-third octave attenuation data for the Kuduwave system is not available or for simplification. [1]

The baseline MPANLs ($L_{LS,max}$) from ISO 8253-1:2010 Table 4 (Bone Conduction, $125\ Hz$ to $8000\ Hz$ test range, $0\ dB\ HL$, values at octave center frequencies) are presented in Table 4a. [1]

Table 4a: ISO 8253-1:2010 Table 4 Baseline MPANLs (Bone Conduction, $0\ dB\ HL$, at Octave Centre Frequencies)

Source: [1]

Frequency (Hz)	$L_{LS,max}$ (dB SPL)
125	20
250	13
500	8

1000	7
2000	8
4000	2
8000	15

These baseline values are added to the Kuduwave's octave band attenuation values (from Table 1 for foam eartips and Table 2 for Silicone (Tympanometry Probe Tip) eartips) to derive the $MPANL_{Kuduwave\_AC\_0\ dB\ HL}$. Subsequently, $15\ dB$ and $25\ dB$ are added to these $0\ dB\ HL$ MPANLs to determine the levels for testing to minimums of $15\ dB\ HL$ and $25\ dB\ HL$, respectively, as per ISO 8253-1, Section 11.1. [1]

Table 4: Calculated Kuduwave AC MPANLs (dB SPL, Octave Bands using ISO 1/3 **Octave Baseline) based on BS EN ISO 8253-1:2010 (Bone Conduction Data for** $0\ dB\ HL$ **Baseline)**

Frequency (Hz)	Eartip Type	ISO 8253-1 MPANL (Bone Cond., $0\ dB\ HL$ at Octave Centre Freq.) (dB SPL)	Kuduwave Combined Attenuation (dB)	Kuduwave AC MPANL ($0\ dB\ HL$) (dB SPL)	Kuduwave AC MPANL ($15\ dB\ HL$) (dB SPL)	Kuduwave AC MPANL ($25\ dB\ HL$) (dB SPL)
125	Foam	20	31.0	**51.0**	66.0	76.0
250	Foam	13	37.7	**50.7**	65.7	75.7
500	Foam	8	43.8	**51.8**	66.8	76.8
1000	Foam	7	40.8	**47.8**	62.8	72.8
2000	Foam	8	38.1	**46.1**	61.1	71.1
4000	Foam	2	52.3	**54.3**	69.3	79.3

8000	Foam	15	45.8	**60.8**	75.8	85.8
125	Silicone	20	9.0	**29.0**	44.0	54.0
250	Silicone	13	10.0	**23.0**	38.0	48.0
500	Silicone	8	30.0	**38.0**	53.0	63.0
1000	Silicone	7	29.7	**36.7**	51.7	61.7
2000	Silicone	8	38.0	**46.0**	61.0	71.0
4000	Silicone	2	44.3	**46.3**	61.3	71.3
8000	Silicone	15	27.0	**42.0**	57.0	67.0

Derived from [1].

The Kuduwave Pro TMP Datasheet also presents MPANLs derived from ISO 8253-1, although it references Table 2 of the standard (supra-aural earphones, one-third octave bands) and then adds the Kuduwave's differential attenuation. [1] The methodology used in Table 4 above, starting from ISO 8253-1's "ears not covered" equivalent (bone conduction MPANLs) and adding the Kuduwave's full octave band attenuation, offers a direct and robust derivation. The inclusion of MPANLs based on this key international ISO standard significantly broadens the applicability and relevance of this white paper for a global audience of clinicians and researchers. [1]

8. Kuduwave AC MPANLs for SANS 10182:2006

SANS 10182:2006 is the South African National Standard governing the measurement and assessment of acoustic environments for audiometric tests. To determine the Kuduwave-specific AC MPANLs based on this standard, the "Ears Not Covered" baseline MPANLs for $0\ dB\ HL$ testing are first identified from SANS 10182. Table 3 of SANS 10182, which specifies MPANLs for sound field audiometry in octave bands, is used here as a conservative "Ears Not Covered" baseline, as sound field conditions generally demand the quietest environments. [1] These baseline values are then combined with the Kuduwave's specific attenuation data for foam and Silicone

(Tympanometry Probe Tip) eartips.

The baseline MPANLs (Lperm) from SANS 10182:2006 Table 3 (Sound Field Audiometry, $0\ dB\ HL$) are presented in Table 5a. [1]

Table 5a: SANS 10182:2006 Table 3 Baseline MPANLs (Sound Field Audiometry, $0\ dB\ HL$)

Source: [1]

Frequency (Hz)	L_{perm} (dB SPL)
125	19.0
250	11.5
500	7.5
1000	6.5
2000	6.0
4000	2.0
8000	11.5

These baseline values are added to the Kuduwave's attenuation values (from Table 1 for foam eartips and Table 2 for Silicone (Tympanometry Probe Tip) eartips presented in Section 4 of this white paper) to derive the $MPANL_{Kuduwave\_AC\_0\ dB\ HL}$. Subsequently, $15\ dB$ and $25\ dB$ are added to these $dB\ HL$ MPANLs to determine the levels for testing to minimums of $15\ dB\ HL$ and $25\ dB\ HL$, respectively. [1]

Table 5: Calculated Kuduwave AC MPANLs (dB SPL, Octave Bands) based on SANS 10182:2006 (Sound Field Audiometry Data for $0\ dB\ HL$ Baseline)

Freque ncy	Eartip	SANS 10182 MPANL (Sound	Kuduwave Combined	Kuduwave AC MPANL	Kuduwave AC MPANL	Kuduwave AC MPANL

(Hz)	Type	Field, $0\ dB\ HL$) (dB SPL)	Attenuation (dB)	($0\ dB\ HL$) (dB SPL)	($15\ dB\ HL$) (dB SPL)	($25\ dB\ HL$) (dB SPL)
125	Foam	19.0	31.0	**50.0**	65.0	75.0
250	Foam	11.5	37.7	**49.2**	64.2	74.2
500	Foam	7.5	43.8	**51.3**	66.3	76.3
1000	Foam	6.5	40.8	**47.3**	62.3	72.3
2000	Foam	6.0	38.1	**44.1**	59.1	69.1
4000	Foam	2.0	52.3	**54.3**	69.3	79.3
8000	Foam	11.5	45.8	**57.3**	72.3	82.3
125	Silicone	19.0	9.0	**28.0**	43.0	53.0
250	Silicone	11.5	10.0	**21.5**	36.5	46.5
500	Silicone	7.5	30.0	**37.5**	52.5	62.5
1000	Silicone	6.5	29.7	**36.2**	51.2	61.2
2000	Silicone	6.0	38.0	**44.0**	59.0	69.0
4000	Silicone	2.0	44.3	**46.3**	61.3	71.3
8000	Silicone	11.5	27.0	**38.5**	53.5	63.5

Derived from [1].

The MPANLs presented in Table 5 are of direct practical utility for Kuduwave users in South Africa and other regions that adhere to or reference SANS 10182. The choice of Sound Field MPANLs from SANS 10182 Table 3 as the "ears not covered" baseline represents a conservative approach, as these are generally the most stringent octave-band values provided in the standard for an unoccluded test type. [1] This selection enhances the robustness and safety margin of the derived Kuduwave MPANLs.

9. Comparison of Calculated ANSI S3.1 MPANLs with Swanepoel et al. (2015)

Swanepoel et al. (2015) conducted research on the Kuduwave audiometer and reported MPANLs for the device when used with insert earphones (foam eartips), based on the ANSI S3.1-1999 (R2013) standard. Their methodology involved taking the ANSI S3.1 MPANLs for standard insert earphones and adding the "Kuduwave attenuation advantage above inserts". This "advantage" represents the additional attenuation provided by the Kuduwave's circumaural earcups over and above that of a standard insert earphone alone. [1]

The MPANLs calculated in this white paper (Section 6, Table 3), also based on ANSI S3.1 for foam eartips, use a different foundational approach:

$$MPANL_{ANSI\_S3.1\_EarsNotCovered} + \alpha_{Kuduwave\_Combined\_Foam}.$$

This method starts from the MPANL for an unoccluded ear and adds the total measured attenuation of the Kuduwave system (earcup + foam eartip). This approach is also consistent with the MPANLs for Kuduwave (foam eartips, ANSI S3.1, $0\ dB\ HL$) presented in the Kuduwave Pro TMP Datasheet. [1]

Table 6 below compares the Kuduwave MPANLs for $0\ dB\ HL$ testing (foam eartips, ANSI S3.1) as reported by Swanepoel et al. (2015) with those calculated in this white paper (which align with the Kuduwave datasheet).

Table 6: Comparison of Kuduwave MPANLs (dB SPL, Foam Eartips, $0\ dB\ HL$, ANSI S3.1 Baseline)

Frequency (Hz)	Swanepoel et al. (2015) Kuduwave MPANL (dB SPL)	White Paper (Table 3) / Kuduwave Datasheet MPANL (dB SPL)	Difference (White Paper - Swanepoel) (dB)
125	67.0	60.0	-7.0

250	59.0	58.7	-0.3
500	60.0	59.8	-0.2
1000	54.0	53.8	-0.2
2000	51.0	52.1	+1.1
4000	59.0	63.3	+4.3
8000	57.0	59.8	+2.8

Source: [1].

Differences arise from the distinct methodologies. The approach in this white paper, adding total Kuduwave attenuation to an "Ears Not Covered" baseline, provides a comprehensive assessment. While Swanepoel et al. (2015) offered valuable early insights, the MPANLs derived herein offer a refined calculation. [1]

10. Kuduwave Bone Conduction (BC) MPANLs

10.1 Introduction to Kuduwave Bone Conduction Testing

Standard BC audiometry uses a bone vibrator on the mastoid with the test ear unoccluded. The Kuduwave performs BC testing with the headset (earcups and eartips) in place, occluding both ears. [1] This leverages the Kuduwave's passive sound attenuation for BC tests. While occlusion can cause the "occlusion effect," the Kuduwave system is designed to compensate for this. [1] The Kuduwave's unique design, allowing BC testing with earcups on, is a significant practical advantage as its inherent sound attenuation also benefits BC testing. Any comprehensive standard for the Kuduwave, including a unified one, must incorporate BC MPANLs that capitalize on this design feature.

10.2 Methodology for Calculating Kuduwave BC MPANLs

The methodology for calculating Kuduwave BC MPANLs mirrors that used for air conduction for $0\ dB\ HL$ testing, by combining the standard's baseline MPANL for unoccluded bone conduction with the Kuduwave's combined sound attenuation:

$$MPANL_{Kuduwave\_BC\_0dBHL}(dB\ SPL)$$
$$= MPANL_{standard\_BC\_EarsNotCovered\_0dBHL}(dB\ SPL) + \alpha_{earcup+eartip}(dB)$$

Where:

- $MPANL_{Kuduwave\_BC\_0dBHL}$ is the maximum permissible external ambient sound pressure level for Kuduwave BC testing to $0\ dB\ HL$.
- $MPANL_{standard\_BC\_EarsNotCovered\_\_0dBHL}$ is the maximum ambient SPL specified by the respective standard for bone conduction audiometry with ears unoccluded (or an equivalent unoccluded baseline), for a $0\ dB\ HL$ minimum test threshold.
- $Attenuation_{earcup+eartip}$ is the combined sound attenuation provided by the Kuduwave earcup and the specific eartip in use (foam or Silicone Tympanometry Probe Tip), as detailed in Table 1 and Table 2 of this white paper. Bone conduction audiometry is clinically performed to determine thresholds at $0\ dB\ HL$; therefore, MPANLs for $15\ dB\ HL$ and $25\ dB\ HL$ are not typically calculated or reported for BC. [1]

10.3 Kuduwave BC MPANLs for ANSI S3.1-1999 (R2013)

For ANSI S3.1-1999 (R2013), the baseline MPANLs for an unoccluded condition ($0\ dB\ HL$) are taken from Table 3 of the standard ("Ears Not Covered", Octave Band data, $125\ Hz$ to $8000\ Hz$ test frequency range, as presented in Table 3a). [1] These baseline values are added to the Kuduwave's combined attenuation (Table 1 for foam, Table 2 for silicone) to derive the Kuduwave BC MPANLs for $0\ dB\ HL$ testing, as shown in Table 7.

Table 7: Calculated Kuduwave BC MPANLs (dB SPL, Octave Bands) based on ANSI S3.1-1999 (Ears Not Covered, $125 - 8000Hz$ Data for $0\ dB\ HL$ Baseline)

Frequency (Hz)	Eartip Type	ANSI S3.1 MPANL (Ears Not Covered, $0\ dB\ HL$) (dB SPL)	Kuduwave Combined Attenuation (dB)	Kuduwave BC MPANL ($0\ dB\ HL$) (dB SPL)
125	Foam	29.0	31.0	60.0

250	Foam	21.0	37.7	58.7
500	Foam	16.0	43.8	59.8
1000	Foam	13.0	40.8	53.8
2000	Foam	14.0	38.1	52.1
4000	Foam	11.0	52.3	63.3
8000	Foam	14.0	45.8	59.8
125	Silicone	29.0	9.0	38.0
250	Silicone	21.0	10.0	31.0
500	Silicone	16.0	30.0	46.0
1000	Silicone	13.0	29.7	42.7
2000	Silicone	14.0	38.0	52.0
4000	Silicone	11.0	44.3	55.3
8000	Silicone	14.0	27.0	41.0

Baseline MPANLs from Table 3a. Attenuation from Tables 1 & 2.

10.4 Kuduwave BC MPANLs for BS EN ISO 8253-1:2010

For BS EN ISO 8253-1:2010, the baseline MPANLs for unoccluded bone conduction ($0\ dB\ HL$) are taken from Table 4 of the standard ("Maximum permissible ambient sound pressure levels in one-third-octave bands, for bone conduction audiometry for hearing threshold level measurements down to $0\ dB$", as presented in Table 4a using values at octave centre frequencies). [1] These baseline values are added to the Kuduwave's combined attenuation (Table 1 for foam, Table 2 for silicone) to derive the Kuduwave BC MPANLs for $0\ dB\ HL$ testing, as shown in Table 8.

Table 8: Calculated Kuduwave BC MPANLs (dB SPL, Octave Bands using ISO 1/3 Octave Baseline) based on BS EN ISO 8253-1:2010 (Bone Conduction Data for $0\ dB\ HL$ Baseline)

Frequency (Hz)	Eartip Type	ISO 8253-1 MPANL (Bone Cond., $0\ dB\ HL$ at Octave Centre Freq.) (dB SPL)	Kuduwave Combined Attenuation (dB)	Kuduwave BC MPANL ($0\ dB\ HL$) (dB SPL)
125	Foam	20	31.0	**51.0**
250	Foam	13	37.7	**50.7**
500	Foam	8	43.8	**51.8**
1000	Foam	7	40.8	**47.8**
2000	Foam	8	38.1	**46.1**
4000	Foam	2	52.3	**54.3**
8000	Foam	15	45.8	**60.8**
125	Silicone	20	9.0	**29.0**
250	Silicone	13	10.0	**23.0**
500	Silicone	8	30.0	**38.0**
1000	Silicone	7	29.7	**36.7**
2000	Silicone	8	38.0	**46.0**
4000	Silicone	2	44.3	**46.3**
8000	Silicone	15	27.0	**42.0**

Baseline MPANLs from Table 4a. Attenuation from Tables 1 & 2.

10.5 Kuduwave BC MPANLs for SANS 10182:2006

For SANS 10182:2006, the baseline MPANLs for unoccluded bone conduction ($0\ dB\ HL$) are taken from Table 2 of the standard. [1] The document 1 notes that Sound Field MPANLs (SANS 10182 Table 3) are more stringent than Bone Conduction MPANLs (SANS 10182 Table 2). [1] While using the Sound Field baseline for BC calculations would be more conservative, Table 9 uses the direct Bone Conduction MPANLs from SANS 10182 Table 2.

The baseline MPANLs (Lperm) from SANS 10182:2006 Table 2 (Bone conduction audiometry, $0\ dB\ HL$) are presented in Table 9a. [1]

Table 9.0: Comparison of SANS 10182:2006 Baseline MPANLs (Sound Field vs. Bone Conduction, $0\ dB\ HL$)

Frequency (Hz)	SANS 10182 MPANL (Sound Field, Table 5a) (dB SPL)	SANS 10182 MPANL (Bone Cond., Table 9a) (dB SPL)	Difference (Sound Field - Bone Cond.) (dB)
125	19.0	22.5	-3.5
250	11.5	14.5	-3.0
500	7.5	10.5	-3.0
1000	6.5	9.5	-3.0
2000	6.0	9.0	-3.0
4000	2.0	5.0	-3.0
8000	11.5	12.5	-1.0

Sources: SANS 10182:2006, Table 2 and Table 3 [1]

Table 9a: SANS 10182:2006 Table 2 Baseline MPANLs (Bone Conduction Audiometry, $0\ dB\ HL$)

Source: [1]

Frequency (Hz)	L_{perm} (dB SPL)
125	22.5
250	14.5
500	10.5
1000	9.5
2000	9.0
4000	5.0
8000	12.5

Table 9: Calculated Kuduwave BC MPANLs (dB SPL, Octave Bands) based on SANS 10182:2006 (Bone Conduction Data for $0\ dB\ HL$ Baseline)

Frequency (Hz)	Eartip Type	SANS 10182 MPANL (Bone Cond., $0\ dB\ HL$) (dB SPL)	Kuduwave Combined Attenuation (dB)	Kuduwave BC MPANL ($0\ dB\ HL$) (dB SPL)
125	Foam	22.5	31.0	**53.5**
250	Foam	14.5	37.7	**52.2**
500	Foam	10.5	43.8	**54.3**
1000	Foam	9.5	40.8	**50.3**
2000	Foam	9.0	38.1	**47.1**
4000	Foam	5.0	52.3	**57.3**
8000	Foam	12.5	45.8	**58.3**

125	Silicone	22.5	9.0	**31.5**
250	Silicone	14.5	10.0	**24.5**
500	Silicone	10.5	30.0	**40.5**
1000	Silicone	9.5	29.7	**39.2**
2000	Silicone	9.0	38.0	**47.0**
4000	Silicone	5.0	44.3	**49.3**
8000	Silicone	12.5	27.0	**39.5**

Derived from [1], Pages 21-22, modified to show $0\ dB\ HL$ only.

10.6 Discussion of Kuduwave Bone Conduction MPANLs

The Kuduwave's approach to bone conduction testing-maintaining an occluded ear condition by keeping the headset in place-allows it to utilize its significant passive sound attenuation. By applying this attenuation to the stringent "ears not covered" or "bone conduction" MPANLs specified in the standards, the Kuduwave can perform BC audiometry in ambient noise conditions that would be too high for traditional unoccluded BC testing. [1]

The calculated Kuduwave BC MPANLs (Table 7 for ANSI S3.1; Table 8 for ISO 8253-1; Table 9 for SANS 10182) provide users with the permissible external ambient noise levels for conducting reliable BC tests to $0\ dB\ HL$. Users must ensure correct software configuration for eartip type and occlusion effect compensation. [1]

11. Proposal for a Unified Global MPANL Standard for the Kuduwave Audiometer

11.1. Rationale for Harmonization: Advancing Boothless Audiometry on a Global Scale

The preceding sections demonstrate that Kuduwave-specific MPANLs can be rigorously derived from various national and international standards (ANSI S3.1, ISO 8253-1, SANS 10182). However, this results in different MPANL values depending on the standard referenced (compare Tables 3, 4, and 5 for AC; and Tables 7, 8, and 9 for BC). For a portable device like the Kuduwave, designed for global use, this variability can introduce complexities for international organizations, multi-site research collaborations, and global deployment strategies. Clinicians and researchers may face uncertainty regarding which standard to apply, potentially leading to inconsistencies in test conditions or requiring adherence to multiple, slightly differing guidelines.

A unified, Kuduwave-specific MPANL standard, harmonizing the best and most protective elements of existing guidelines, would offer significant advantages. It would provide unparalleled clarity and consistency for users worldwide, simplify training and operational protocols, enhance user confidence, and streamline regulatory considerations. Moreover, such a standard would represent a pioneering step in establishing device-specific international guidelines for the rapidly evolving field of boothless audiometry, promoting a consistent quality of care globally.

11.2. Synthesizing Best Practices from Existing International Standards

The proposed unified Kuduwave MPANL standard is built upon the robust methodologies and principles already discussed, aiming to synthesize them into a single, comprehensive framework.

- **A. Selection of a Consistent "Ears Not Covered" / Unoccluded Baseline Reference:**
  The "ears not covered" or equivalent unoccluded baseline MPANLs from ANSI S3.1 (Table 3a), ISO 8253-1 (Table 4a, using bone conduction values as a proxy for an unoccluded ear condition for AC baseline derivation), and SANS 10182 (Table 5a for AC-related baseline) exhibit variations (see Appendix Tables A1.1, A1.2, A1.3). To create a unified baseline that offers the highest probability of valid audiograms across diverse interpretations of acceptable noise, a conservative approach is adopted.
  - **Proposal for Unified Baseline:** A single "Unified Baseline MPANL (Ears Not Covered, $0\ dB\ HL$)" will be established. This baseline, at each octave band frequency ($125\ Hz$ to $8000\ Hz$), will be the **most stringent (i.e., lowest dB SPL value)** derived from the "ears not covered" (or equivalent for AC) data from ANSI S3.1-1999 Table 3 (Table 3a), BS EN ISO 8253-1:2010 Table 4 (Table 4a, used as a proxy for an unoccluded ear condition), and SANS 10182:2006

Table 3 (Sound Field, Table 5a). The derivation of this single unified baseline is detailed in Appendix Table A3.1. This strategic choice of the most stringent values from AC-related unoccluded conditions ensures that the unified standard errs on the side of caution, maximizing the likelihood of obtaining unmasked hearing thresholds for both air and bone conduction testing performed with the Kuduwave under this unified framework. For the purpose of this unified standard, this single baseline will be used for calculating both AC and BC Kuduwave MPANLs, promoting simplicity and maximum stringency, particularly given the Kuduwave's occluded-ear testing methodology for both AC and BC.

- **B. Standardized Application of Device-Specific Attenuation:**
  The core calculation principle remains:

  $$Unified\_MPANL_{Kuduwave} = Unified\_Baseline_{MPANL} + \alpha_{Kuduwave\_Combined}$$

  The established Kuduwave combined sound attenuation data for foam eartips (Table 1) and silicone (Tympanometry Probe Tip) eartips (Table 2) will be applied separately, acknowledging the critical impact of eartip choice on noise reduction.

- **C. Uniform Adjustments for Minimum Test Thresholds:**
  For air conduction, the universally accepted principle of adding $15\ dB$ or $25\ dB$ to the $0\ dB\ HL$ MPANL to derive values for $15\ dB\ HL$ and $25\ dB\ HL$ minimum test thresholds, respectively, will be adopted. [1] This aligns with ANSI S3.1, ISO 8253-1, and ISO 6189, ensuring consistency with established audiometric practice. For bone conduction under this unified standard, MPANLs are presented for $0\ dB\ HL$ testing, using the same $0\ dB\ HL$ MPANL values as derived for air conduction from the common unified baseline.

- **D. Approach to Frequency Bandwidth:**
  The unified standard will specify MPANLs in octave bands from $125\ Hz$ to $8000\ Hz$. This is consistent with the Kuduwave MPANL calculations presented earlier, aligns with the common presentation of Kuduwave's attenuation data, and suits practical field measurements, even though some standards like ISO 8253-1 also provide one-third octave band data.

11.3. Framework for the Proposed Unified Kuduwave MPANL Standard

The calculation steps are:

1. Establish the "Unified Baseline MPANL (Ears Not Covered, $0\ dB\ HL$)" by selecting the most stringent value at each octave frequency from ANSI S3.1 Table 3 (Table 3a), ISO 8253-1 Table 4 (Table 4a, as proxy), and SANS 10182 Table 3 (Table 5a) (see Appendix Table A3.1).
2. For both AC and BC testing: Unified_MPANLKuduwave_0 dB HL = Unified Baseline + AttenuationKuduwave_Combined (for foam or silicone eartips).
3. Adjust for higher minimum test thresholds for AC: Add 15 dB for 15 dB HL testing, and 25 dB for 25 dB HL testing, to the Unified_MPANLKuduwave_0 dB HL values. For BC, the Unified_MPANLKuduwave_0 dB HL values apply.

11.4. Illustrative Unified Kuduwave MPANL Values

The following table presents the proposed unified MPANLs for the Kuduwave, calculated according to the framework described above. This table aims to provide clinicians and researchers with a single, globally applicable set of MPANL values, promoting consistency and simplifying decisions regarding test environments for both air and bone conduction.

Table 10: Proposed Unified Kuduwave MPANLs (dB SPL, Octave Bands) for Air Conduction (AC) and Bone Conduction (BC)

Freq. (Hz)	Eartip Type	Unified Baseline MPANL (Ears Not Covered, $0\ dB\ HL$) (dB SPL)	Kuduwave Combined Attenuation (dB)	Unified Kuduwave MPANL ($0\ dB\ HL$) (AC & BC) (dB SPL)	Unified Kuduwave AC MPANL ($15\ dB\ HL$) (dB SPL)	Unified Kuduwave AC MPANL ($25\ dB\ HL$) (dB SPL)
125	Foam	19.0	31.0	**50.0**	65.0	75.0
250	Foam	11.5	37.7	**49.2**	64.2	74.2
500	Foam	7.5	43.8	**51.3**	66.3	76.3
1000	Foam	6.5	40.8	**47.3**	62.3	72.3
2000	Foam	6.0	38.1	**44.1**	59.1	69.1

4000	Foam	2.0	52.3	**54.3**	69.3	79.3
8000	Foam	11.5	45.8	**57.3**	72.3	82.3
125	Silicone	19.0	9.0	**28.0**	43.0	53.0
250	Silicone	11.5	10.0	**21.5**	36.5	46.5
500	Silicone	7.5	30.0	**37.5**	52.5	62.5
1000	Silicone	6.5	29.7	**36.2**	51.2	61.2
2000	Silicone	6.0	38.0	**44.0**	59.0	69.0
4000	Silicone	2.0	44.3	**46.3**	61.3	71.3
8000	Silicone	11.5	27.0	**38.5**	53.5	63.5

Unified Baseline derived in Appendix A3.1. Attenuation from Tables 1 & 2. The "Unified Kuduwave MPANL ($0\ dB\ HL$)" column applies to Air Conduction at $0\ dB\ HL$ and all Bone Conduction testing (to $0\ dB\ HL$) under this unified standard.

11.5. Advantages, Implementation Considerations, and Future Validation

- **Advantages:** The primary advantage of this proposed unified standard is global consistency, leading to simplified test protocols, reduced ambiguity for users, and enhanced comparability of data from Kuduwave audiometers used in different regions or by different organizations. It supports international research collaborations and facilitates more straightforward training and quality assurance. A particularly powerful implementation pathway exists through potential integration into the Kuduwave's software. If the Kuduwave's real-time noise monitoring system allowed users to select this "Unified Kuduwave Standard" as their reference, the device itself would guide adherence, leveraging its existing conservative $SPHL_{in-ear}$ calculations (including the $+\ 3\ dB\ SPL$ offset).[1] This would make the unified standard immediately actionable and highly practical for users.
- **Implementation Considerations:** Successful adoption requires dissemination of

these guidelines through publications, presentations, and training materials. Engagement with professional audiology bodies and standards organizations could foster broader recognition and potential incorporation into future best-practice recommendations for boothless audiometry.

- **Future Validation:** While derived from established principles and data, ongoing validation of these unified MPANLs in diverse real-world clinical and field settings is recommended. Multi-center studies comparing audiometric outcomes under conditions compliant with this unified standard versus traditional booth-based audiometry could further solidify its evidence base. This proactive approach to developing a device-specific global MPANL standard is innovative and positions the Kuduwave at the forefront of promoting best practices in advanced audiometry.

12. Discussion

The MPANLs calculated in Tables 3, 4, and 5 for air conduction, and Tables 7, 8, and 9 for bone conduction, provide essential, standards-based guidance for utilizing the Kuduwave audiometer effectively across diverse environments. [1] These tables empower users to make informed decisions about the suitability of a test location by comparing measured ambient noise levels against the Kuduwave's capabilities when using specific eartips and targeting particular minimum hearing levels (for AC) or $0\ dB\ HL$ (for BC). The very need to calculate these Kuduwave-specific MPANLs arises from its advanced dual passive attenuation system, which offers significantly different noise reduction than standard earphones covered by generic MPANL tables in audiometric standards.

The introduction of the proposed Unified Global MPANL Standard for the Kuduwave (Section 11, Table 10) represents a significant step beyond adherence to individual existing standards. This proposal addresses the inherent variability and potential confusion arising from multiple guidelines by offering a single, consolidated, and highly protective set of MPANLs for both air and bone conduction. The advantages are manifold: enhanced clarity and confidence for users globally, simplification of testing protocols for multinational organizations or international research consortia, and a more consistent approach to quality assurance in hearing assessment programs. The development of such a unified standard, by selecting the most stringent "ears not covered" baseline values from respected international standards (primarily those related to AC testing or their equivalents) and applying it for both AC and BC Kuduwave MPANL calculations, ensures that it prioritizes test accuracy and patient safety above all.

A critical aspect of the Kuduwave's utility is its built-in real-time ambient noise monitoring system, including the $SPHL_{in-ear}$ display and the conservative $+\ 3\ dB\ SPL$ offset in its internal calculations. [1] This feature, which already provides a safety margin when testing against existing standards, would synergize powerfully with the proposed unified standard. If Kuduwave software were updated to allow users to select the "Unified Kuduwave Standard" as their reference for noise monitoring, the device would intrinsically guide them towards compliance with these new, globally harmonized MPANLs. This practical integration would make the unified standard not just a theoretical construct but an actionable tool, further simplifying its adoption and ensuring its benefits are readily accessible to all Kuduwave users. The device's capability to capture transient sounds within 100-millisecond windows further enhances its ability to ensure valid test conditions under this unified framework. [1]

Regardless of whether users adhere to MPANLs derived from existing individual standards or the proposed unified standard, best practices for minimizing ambient noise remain paramount. This includes careful site selection, testing during quieter periods, and controlling local noise sources. [1] The substantial differences in attenuation between foam and silicone eartips also highlight the non-negotiable importance of correct eartip selection (and corresponding software configuration) and meticulous, deep insertion to achieve the documented attenuation levels. [1] An improper fit will compromise the very foundation upon which these MPANLs are built.

The work presented in this white paper, encompassing both the calculation of MPANLs against existing standards and the proposal for a unified Kuduwave standard, significantly contributes to the evidence base supporting validated boothless audiometry. The systematic methodology for deriving a device-specific unified MPANL, based on leveraging a device's unique attenuation characteristics against a conservatively chosen harmonized baseline, could also serve as a valuable model for other advanced audiometric systems. As boothless technologies become increasingly prevalent, such clear, evidence-based, and globally harmonized guidelines will be essential for ensuring the continued reliability and validity of hearing assessments conducted outside traditional sound-treated environments.

13. Conclusion

This white paper has successfully established and presented specific MPANLs for the

GeoAxon Kuduwave audiometer, covering both air conduction and bone conduction testing. These MPANLs have been meticulously calculated in accordance with three prominent standards—ANSI S3.1-1999 (R2013), BS EN ISO 8253-1:2010, and SANS 10182:2006—a necessary undertaking due to the Kuduwave's unique dual passive attenuation system. For air conduction, MPANLs address minimum test thresholds of $0\ dB\ HL$, $15\ dB\ HL$, and $25\ dB\ HL$. For bone conduction, MPANLs are provided for $0\ dB\ HL$ testing. All calculations consider both foam and Silicone Tympanometry Probe Tip eartip configurations. [1]

A key finding, consistently demonstrated, is that the Kuduwave audiometer, owing to its significant sound attenuation capabilities, permits accurate hearing assessments in ambient noise conditions that are considerably higher than those allowable for unoccluded testing or testing with conventional supra-aural earphones. [1] This capability is fundamental to its role as a validated boothless audiometry solution.

The principal new contribution of this expanded white paper is the proposal for a **Unified Global MPANL Standard for the Kuduwave Audiometer**. This proposal, detailed in Section 11, synthesizes the most protective elements of existing international standards to derive a single, robust set of guidelines applicable to both air and bone conduction. By establishing a single harmonized "ears not covered" baseline from the most stringent values of current standards and applying the Kuduwave's empirically determined attenuation, this unified standard (Table 10) aims to provide maximum clarity, consistency, and confidence for Kuduwave users worldwide. It is designed to simplify international research, streamline global deployment, and ensure a consistently high standard of test validity.

The Kuduwave's integrated real-time noise monitoring system, with its conservative internal processing (including the $+\ 3\ dB\ SPL$ offset for its $SPHL_{in-ear}$ calculation) [1], provides users with immediate and reliable feedback on the suitability of the test environment. This feature is particularly synergistic with the proposed unified standard, offering a practical pathway for its implementation directly within the device software.

Ultimately, this comprehensive set of MPANLs—both those derived from individual standards and the forward-looking unified standard—empowers occupational health professionals, clinicians, and researchers. It enables them to confidently deploy the Kuduwave in diverse settings, extending the reach of reliable hearing healthcare and facilitating versatile research. The Kuduwave, guided by these evidence-based acoustic parameters and particularly by the potential adoption of the proposed unified standard, is well-positioned to continue advancing modern audiological practice and significantly enhance global access to essential hearing assessment services. This work not only serves as a practical guide but also as a contribution to the evolving landscape of standards for innovative audiometric technologies.

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15. Appendix

A1: Source MPANL Data from Standards ($0\ dB\ HL$, "Ears Not Covered" / Equivalent, Octave Bands)

Table A1.1: ANSI S3.1-1999 (R2013) - Table 3 (Ears Not Covered, Octave Bands, 125-8000Hz range, $0\ dB\ HL$) - Used for AC and BC Calculations (and Unified Baseline)

Source: [1].

Frequency (Hz)	MPANL (dB SPL)
125	29.0
250	21.0
500	16.0
1000	13.0
2000	14.0
4000	11.0
8000	14.0

Table A1.2: BS EN ISO 8253-1:2010 - Table 4 (Bone Conduction, 1/3 Octave Bands at Octave Centre Frequencies, 125-8000Hz range, $0\ dB\ HL$) - Used for AC and BC Calculations (and as proxy for ENC in Unified Baseline)

Source: [1].

Octave Centre Frequency (Hz)	ISO 8253-1 MPANL ($L_{S,max}$) (dB SPL) from 1/3 Octave Band
125	20
250	13
500	8

1000	7
2000	8
4000	2
8000	15

Table A1.3: SANS 10182:2006 - Table 3 (Sound Field Audiometry, Octave Bands, $0\ dB\ HL$) - Used for AC Calculations (and Unified Baseline)

Source: 1.

Frequency (Hz)	MPANL (L_{perm}) (dB SPL)
125	19.0
250	11.5
500	7.5
1000	6.5
2000	6.0
4000	2.0
8000	11.5

Table A1.4: SANS 10182:2006 - Table 2 (Bone Conduction Audiometry, Octave Bands, $0\ dB\ HL$) - Used for BC Calculations

Source: [1].

Frequency (Hz)	MPANL (Lperm) (dB SPL)
125	22.5
250	14.5
500	10.5
1000	9.5
2000	9.0
4000	5.0
8000	12.5

A2: Kuduwave Combined Sound Attenuation Data (Consolidated)

Table A2.1: Kuduwave Combined Sound Attenuation - Foam Eartips (dB)

Frequency (Hz)	Attenuation (dB)
125	31.0
250	37.7
500	43.8
1000	40.8
2000	38.1
4000	52.3
8000	45.8

Source: Kuduwave Pro TMP Datasheet; Consistent with Swanepoel et al., 2015.[1]

Table A2.2: Kuduwave Combined Sound Attenuation - Silicone (Tympanometry Probe Tip) eartips (dB)

Frequency (Hz)	Attenuation (dB)
125	9.0
250	10.0
500	30.0
1000	29.7
2000	38.0
4000	44.3
8000	27.0

Source: Kuduwave Pro TMP Datasheet; Identical to Ramatshoma et al., 2021.[1]

A3: Derivation of Unified Baseline MPANL ($0\ dB\ HL$, Octave Bands)

Table A3.1: Derivation of Unified Baseline MPANL (Ears Not Covered, $0\ dB\ HL$, Octave Bands) for the Proposed Unified Kuduwave Standard

Freq. (Hz)	ANSI S3.1 T3 (Ears Not Covered) (dB SPL) (from A1.1)	ISO 8253-1 T4 (BC as proxy for ENC) (dB SPL) (from A1.2)	SANS 10182 T3 (Sound Field) (dB SPL) (from A1.3)	Proposed Unified Baseline (dB SPL) (Most Stringent)	Source of Stringent Value
125	29.0	20	19.0	**19.0**	SANS
250	21.0	13	11.5	**11.5**	SANS
500	16.0	8	7.5	**7.5**	SANS

1000	13.0	7	6.5	**6.5**	SANS
2000	14.0	8	6.0	**6.0**	SANS
4000	11.0	2	2.0	**2.0**	ISO / SANS
8000	14.0	15	11.5	**11.5**	SANS