ISSN: 2083-389X
eISSN: 2084-3127

J Hear Sci, 2025; 15(4): 9–15
DOI: 10.17430/jhs/216756
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Received:
August 21, 2025
Revision accepted:
January 21, 2026
Published online:
February 2, 2026

MASKING TECHNIQUES REVISITED: APPLICATION OF LIDÉN'S FORMULAS IN BONE CONDUCTION SPEECH AUDIOMETRY

Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

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Abstract

Introduction: Bone conduction speech audiometry is a complementary tool required by many otologists, particularly in assessing cochlear reserve and estimating postoperative results in patients undergoing stapedectomy. However, when clinical masking of the non-test ear is needed for these tests, it introduces a significant methodological challenge. This study aims to establish a systematic approach for determining safe and effective masking levels in bone conduction speech audiometry. In this context, the proposed framework offers quantitative tools designed to help reduce the risk of masking dilemmas, which are a persistent challenge in audiologic practice.

Material and methods: Adaptation and application of Lidén's formulas to determine the minimum and maximum masking levels for bone conduction speech audiometry and analysis of four frequently encountered audiometric configurations.

Results: The minimum and maximum masking levels for each configuration were determined. In cases of large ear-bone gaps in the non-test ear, and/or good bone conduction thresholds in the test ear, masking at supra-threshold levels may be difficult due to the risk of overmasking. In one or more of these configurations, a masking dilemma is sometimes detected at levels close to the speech recognition threshold. In such challenging situations, we recommend the use of insert earphones to extend the range of safe stimulus levels and masking levels that can be presented to the patient.

Conclusions: Speech audiometry holds considerable predictive value for otologic surgeons, so it is important to use techniques that minimise the risks of cross-hearing and inappropriate masking. These limitations are important when using bone-conduction stimulation and need to be carefully evaluated. This paper shows how Lidén's formulas can be used for calculating safe masking levels.

Keywords: diagnostic techniques • speech audiometry • clinical masking • bone conduction • Lidén's formulas

PONOWNE SPOJRZENIE NA TECHNIKI MASKOWANIA: ZASTOSOWANIE WZORÓW LIDÉNA W AUDIOMETRII SŁOWNEJ DLA PRZEWODNICTWA KOSTNEGO

Streszczenie

Wprowadzenie: Audiometria słowna dla przewodnictwa kostnego jest narzędziem uzupełniającym wymaganym przez wielu otologów, szczególnie w ocenie rezerwy ślimakowej i szacowaniu wyników pooperacyjnych u pacjentów poddanych stapedektomii. Jednak gdy do wykonania tych badań konieczne jest kliniczne maskowanie ucha niepoddawanego badaniu, stanowi to poważne wyzwanie metodologiczne. Niniejsze badanie ma na celu ustalenie podejścia systematycznego do określania bezpiecznych i skutecznych poziomów maskowania w audiometrii słownej dla przewodnictwa kostnego. W tym kontekście proponowane ramy oferują narzędzia ilościowe zaprojektowane w celu zmniejszenia problemów związanych z maskowaniem, które stanowią stałe wyzwanie w praktyce audiologicznej.

Materiał i metody: Adaptacja i zastosowanie wzorów Lidéna do określenia minimalnych i maksymalnych poziomów maskowania w audiometrii dla przewodnictwa kostnego oraz analiza czterech często spotykanych konfiguracji audiometrycznych.

Wyniki: Określono minimalne i maksymalne poziomy maskowania dla każdej konfiguracji. W przypadku dużej różnicy między przewodnictwem powietrznym a kostnym w uchu niebadanym i/lub prawidłowych progów przewodnictwa kostnego w uchu badanym maskowanie na poziomach powyżej progu może być trudne ze względu na ryzyko nadmiernego maskowania. W jednej lub kilku z tych konfiguracji czasami pojawia się problem maskowania na poziomach zbliżonych do progu rozpoznawania mowy. W tych sytuacjach zalecamy stosowanie słuchawek dousznych w celu poszerzenia zakresu bezpiecznych poziomów bodźców i poziomów maskowania, które można zastosować u pacjenta.

Wnioski: Audiometria słowna ma duże znaczenie prognostyczne dla otochirurgów, dlatego ważne jest stosowanie technik minimalizujących ryzyko słyszenia krzyżowego i nieodpowiedniego maskowania. Ograniczenia te są istotne w przypadku stosowania stymulacji w przewodnictwie kostnym i wymagają dokładnej oceny. Niniejszy artykuł pokazuje, w jaki sposób można wykorzystać wzory Lidéna do obliczania bezpiecznych poziomów maskowania.

Słowa kluczowe: techniki diagnostyczne • audiometria słowna • maskowanie kliniczne • przewodnictwo kostne • wzory Lidéna

Key to abbreviations	
ABG	air-bone gap
BEST_BC_NTE	best bone-conduction threshold for non-test ear
BEST_BC_TE	best bone-conduction threshold for test ear
IA_AC	interaural attenuation for air conduction
IA_BC	interaural attenuation for bone conduction
MAX_GAP_NTE	maximum air-bone gap in non-test ear
MAX_MASK	maximum masking level
MID_MASK	mid masking level
MIN_MASK	minimum masking level
NTE	non-test ear
PL_TE	presentation level at test ear
PTA	pure tone average
SDT	speech detection threshold
SRT	speech recognition threshold
TE	test ear
WRS	word recognition score

Introduction

Despite a small number of papers in the field, some authors have highlighted the usefulness of assessing bone conduction speech thresholds. Kruger & Mazor [1] noted that the speech detection threshold (SDT) and speech recognition threshold (SRT), typically measured through air conduction, can also be determined for bone conduction. They argue that in this way it is feasible to detect the presence of an air–bone gap and estimate its magnitude in cases where it is difficult to obtain responses through pure tones, such as in children or other hard-to-test patients. Bone-conduction SRT correlates well with the average bone thresholds at 500, 1000, and 2000 Hz, whereas bone-conduction SDT demonstrates good correlation with the bone threshold at 250 Hz.

The use of bone-conduction speech thresholds in situations where pure-tone audiometry is difficult to perform is a useful approach for evaluating the likely outcomes of stapedectomy surgeries. Goetzinger & Proud [2] proposed using the bone-conduction SRT as a complement to bone-conduction pure tone audiometry. They collected data from 353 ears in patients aged 5–64 years. The relationship between the bone conduction SRT and the bone-conduction pure-tone average (PTA) exhibited a high positive correlation ($r = 0.90$), comparable to that found for air conduction stimulation. Merrel et al. [3] emphasised the usefulness of bone and air conduction speech thresholds, particularly in pediatric cases, allowing for better differentiation between conductive and sensorineural hearing loss than does pure-tone audiometry. Goetzinger & Proud [2] also reported obtaining the word recognition score (WRS) at a level 25 dB above the SRT, with scores of 90–100% being typical of normal-hearing individuals and patients with conductive hearing loss, whereas individuals with sensorineural losses exhibited varying degrees of discrimination difficulty. However, the core of their work was to explain the utility of obtaining speech recognition thresholds.

In other work, Hahlbrock [4] explained that bone-conduction pure-tone audiometry may yield erroneous results at frequencies below 1000 Hz due to the perception of the tone through tactile vibration rather than through the auditory system. Differentiating between real auditory perception and tactile sensation is not always possible with a yes/no response method like pure-tone audiometry. This may result in an overestimation of cochlear reserve, and he therefore suggested the use of bone-conduction speech audiometry as a more appropriate technique. The same author cited earlier work by Tato & Alfaro [5] who suggested that using bone-conduction speech discrimination provides validation of an air-conduction test. They reported that bone-conduction speech discrimination scores obtained at a comfortable listening level had great diagnostic value in terms of the degree of sensorineural deterioration, and considered that patients with recognition scores above 80% were good candidates for surgery.

Robinson & Kasden [6,7] pointed out that preoperative bone-conduction speech discrimination is an accurate way of measuring cochlear reserve in patients with otosclerosis. They illustrated several cases where the use of bone-conduction recognition scores was an excellent predictor of postoperative outcomes. However, they made an important caveat regarding the feasibility of performing such studies, which relates to the maximum stimulation level allowed by both the audiometer and bone vibrator. For bone conduction, the maximum stimulus level for speech was 55 dB HL (in current audiometers, it is 60 dB HL), imposing an upper limit on presentation levels. The authors said that reaching higher stimulus levels required an additional amplifier and bone transducer capable of delivering a more powerful and distortion-free signal. Such a necessity may explain the limited spread of this methodology, given the requirement for an additional amplifier whose output must be calibrated separately. WRS values were obtained at the most comfortable loudness level for the TE, with the maximum acceptable masking applied to the NTE.

In related technical work, Barry & Gaddis [8] did not criticise the use of bone-conduction speech audiometry per se, but warned about the maximum stimulus presentation levels beyond which appreciable distortion may occur. In addition to the limitations imposed by the maximum level of speech stimulus that can be presented through bone conduction, the most important limitation to consider is the risk of cross-hearing.

Given these technical and methodological challenges, the present work aims to establish a reliable framework for calculating, using Lidén's formulas, safe masking levels in bone conduction speech audiometry. By analysing common audiometric configurations, this study seeks to support clinicians in minimising the risk of overmasking and cross-hearing, thereby improving the accuracy and clinical utility of speech-based bone conduction assessments. Although there are well-established references regarding the clinical application of masking for pure-tone audiometry and airconduction speech audiometry, little has been written about the application of masking in boneconduction speech audiometry. Since masking continues to be widely used, it is important to analyse it in detail and to construct a solid theoretical foundation for its use.

Material and methods

The need for masking in bone-conduction speech audiometry

The abbreviations used here are derived from those used by Yacullo [9] and Turner [10]. According to the theory of clinical masking in speech audiometry, the interaural attenuation (IA) for a stimulus applied via bone conduction is very low. It is generally assumed, as a conservative criterion, to be zero (IA_BC = 0). Therefore, when speech material is presented to the test ear (TE) at a certain presentation level (PL_TE), that same stimulus level also reaches the non-test ear (NTE). Hence, if the level presented to the TE exceeds the best bone-conduction threshold of the NTE, the information reaching this ear may be enough for recognition. Consequently, the basic criterion for deciding the need for masking in bone-conduction speech audiometry is:

$$\text{PL\_TE-IA\_BC} \geq \text{BEST\_BC\_NTE}$$

and, since IA_BC = 0,

$$\text{PL\_TE} \geq \text{BEST\_BC\_NTE} \quad (1)$$

In this formula, it is considered that the best bone conduction threshold of the non-test ear could be responsible for speech recognition by the non-test ear. This criterion is included in the ASHA [11] publication. This implies that masking should be applied whenever the presentation level of the stimulus in the test ear exceeds the best bone conduction threshold in the non-test ear within the 500–4000 Hz range.

Lidén's formulas for minimum and maximum masking levels in bone conduction

If masking is required, the level to be applied should be enough to prevent the non-test ear from recognising the stimulus presented to the test ear, but not so intense as to cause overmasking. Such overmasking occurs when the masking noise applied to the non-test ear crosses over and masks the perception of the stimulus in the test ear. Following the same rationale used in speech audiometry with air conduction, works by Yacullo [9] and Alonso et al. [12] showed that it is advisable to place the masking level in the mid-plateau region. The plateau is bounded by minimum and maximum masking values.

Lidén's formulas [13] are the theoretical basis for masking of pure tone stimuli via both air and bone conduction, as well as speech stimuli via air conduction. They can also be applied to bone conduction to determine the minimum and maximum masking levels.

$$\text{MIN\_MASK} = \text{PL\_TE} - \text{IA\_BC} + \text{MAX\_GAP\_NTE}$$
$$\text{MAX\_MASK} = \text{BEST\_BC\_TE} + \text{IA\_AC} - 5\ \text{dB}$$

IA_BC refers to the interaural attenuation value for stimuli presented by bone conduction, which is generally considered to be 0 dB. On the other hand, IA_AC is the interaural attenuation for stimuli delivered through air conduction using headphones, and its value depends on the type of transducer used for masking. Considering that for bone conduction, IA_BC = 0, the above expressions can be simplified as follows:

$$\text{MIN\_MASK} = \text{PL\_TE} + \text{MAX\_GAP\_NTE} \quad (2)$$
$$\text{MAX\_MASK} = \text{BEST\_BC\_TE} + \text{IA\_AC} - 5\ \text{dB} \quad (3)$$

Since masking is always applied through headphones, the IA value to be used in the MAX_MASK formula corresponds to this type of transducer. Therefore, IA_AC = 40 dB (or 60 dB if insert earphones are used). The term MAX_GAP_NTE refers to the maximum air-bone gap in the range 500 to 4000 Hz in the non-test ear.

These formulas demonstrate that, for a given presentation level, the relevant variables to consider in the pure tone audiogram are the largest air-bone gap in the non-test ear and the best bone conduction threshold in the test ear. A reduced air-bone gap in the non-test ear requires a lower minimum masking level; conversely, a poorer bone conduction threshold in the test ear allows for a higher maximum masking level without introducing overmasking. The optimal situation occurs when MAX_GAP_NTE = 0 and BC_TE is high. The worst-case scenario is the opposite, where MAX_GAP_NTE is maximal and BC_TE = 0. Yacullo [14] recommends using a masking level in the middle of both limits, so that

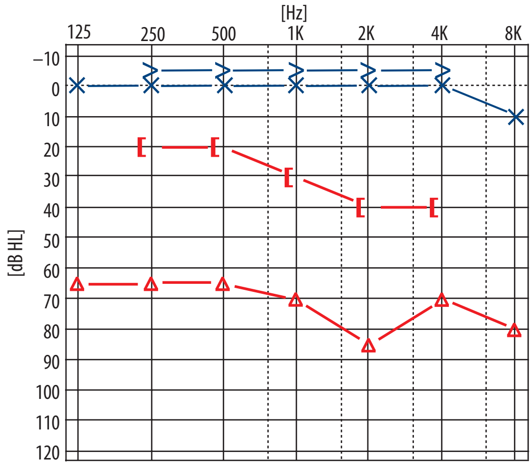
$$\text{MID\_MASK} = (\text{MIN\_MASK} + \text{MAX\_MASK})/2$$

Occlusion effect in bone conduction speech audiometry

Gelfand & Calandruccio [15] emphasised the need to account for the occlusion effect when calculating masking levels for bone conduction speech audiometry. Based on the measurements reported by Klodd & Edgerton [16], it is recommended to adjust the formula for minimum masking as follows:

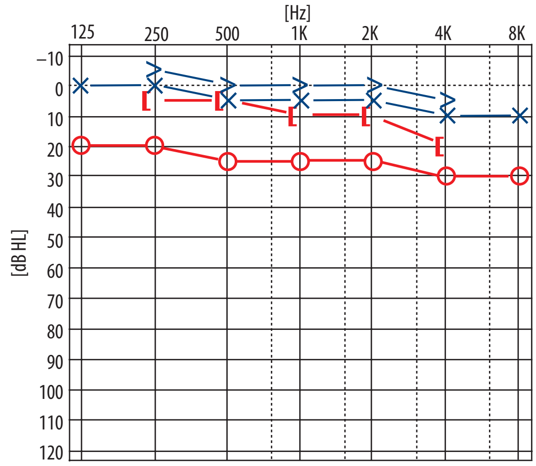
$$\text{MIN\_MASK} = \text{PL\_TE} + \text{MAX\_GAP\_NTE} + \text{OE} \quad (2')$$

This corresponds to formula (2) with the addition of a compensation term for the occlusion effect. These authors recommend using an OE value of 18 dB when the bone vibrator is placed on the mastoid and 23 dB when placed



BEST_BC_NTE	–5
MAX_GAP_NTE	5
BEST_BC_TE	20

Figure 1. Mixed hearing loss in the test ear; normal hearing in the non-test ear. The numbers below the audiogram list the variables used in the formula



BEST_BC_NTE	0
MAX_GAP_NTE	5
BEST_BC_TE	5

Figure 2. Conductive hearing loss in the test ear. Normal non-test ear

on the vertex. Their conclusions were based on measurements obtained using circumaural headphones. To date, no comparable measurements have been found for insert earphones. However, considering that the occlusion effect for tonal stimuli only affects the 250 Hz frequency when this kind of transducer is used [17], it may be concluded that, for them, the influence (if any) would be minimal and practically negligible. This additionally substantiates the use of insert earphones for masking in bone conduction speech audiometry, particularly when they are deeply inserted in the ear canal, as this minimises the occlusion effect [18]. Furthermore, it should be remarked that if the non-test ear presents a conductive component, compensation for the occlusion effect is not necessary [17].

Results

Application of Lidén formulas to different audiogram configurations

In the following cases, masking will be applied to obtain bone conduction speech audiometry in the right ear (TE). Four audiometric configurations frequently observed in clinical practice are analysed, illustrating the influence of multiple variables that must be considered. It is also assumed that a circumaural earphone is used for masking, unless another option is explicitly stated. The tabulated numbers below each audiogram show the variables used in the formulas. Formula (1) is used to check if masking is required, and formulas (2 or 2') and (3) are for MIN_MASK and MAX_MASK calculations.

Case 1. TE: mixed hearing loss; NTE: normal hearing (Figure 1)

Need for masking
PL_TE ≥ BEST_BC_NTE
PL_TE ≥ – 5 dB.

This means that for any stimulus level presented to the right ear (TE), masking should be applied.

Minimum masking level
MIN_MASK = PL_TE + MAX_GAP_NTE + OE
MIN_MASK = PL_TE + 5 dB + 18 dB = PL_TE + 23 dB

Maximum masking level
MAX_MASK = BEST_BC_TE + IA_AC – 5 dB
MAX_MASK = 20 + 40 dB – 5 dB = 55 dB.

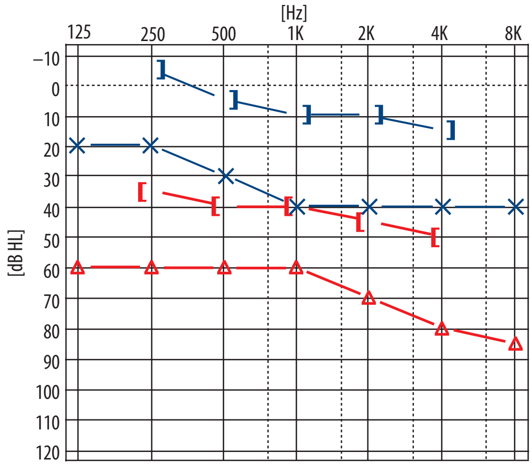
In this example, it is feasible to obtain bone-conduction SRT close to the bone-conduction PTA (30 dB). Obtaining some WRS at a supra-threshold level requires increasing the presentation level. If the presentation level at the TE is 40 dB, then MIN_MASK = 40 + 5 + 18 = 63 dB. The MIN_MASK is greater than the MAX_MASK. This is a masking dilemma: the minimum masking required is greater than the maximum permissible. The use of an insert earphone for masking delivery in the NTE can raise by 20 dB the maximum masking allowed. In this case, the applicable allowed masking values are from 63 to 75 dB.

Case 2. Single-sided hearing loss. TE: conductive hearing loss; NTE: normal hearing (Figure 2)

Need for masking
PL_TE ≥ BEST_BC_NTE
PL_TE ≥ 0

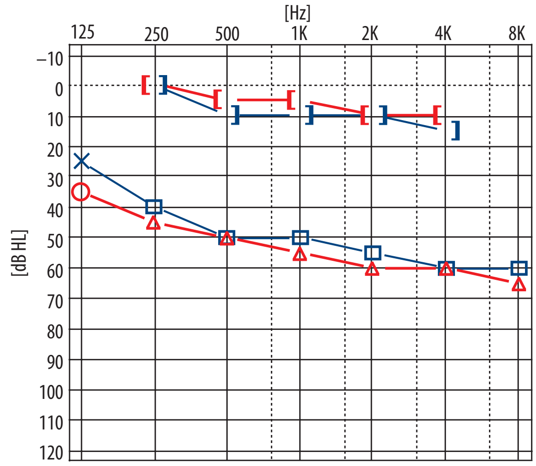
Thus, for any stimulus level presented to the right ear (TE), masking should be applied.

Minimum masking level
MIN_MASK = PL_TE + MAX_GAP_NTE + OE
MIN_MASK = PL_TE + 5 dB + 18 dB = PL_TE + 23 dB



BEST_BC_NTE	5
MAX_GAP_NTE	30
BEST_BC_TE	40

Figure 3. Mixed hearing loss in the test ear; conductive loss in the non-test ear



BEST_BC_NTE	10
MAX_GAP_NTE	45
BEST_BC_TE	5

Figure 4. Bilateral conductive hearing loss

Maximum masking level
MAX_MASK = BEST_BC_TE + IA_AC – 5 dB
MAX_MASK = 5 + 40 dB – 5 dB = 40 dB

There should be no issue obtaining the SRT in the right ear (TE) with presentation levels close to the bone PTA (10 dB). If PL_TE exceeds 20 dB, there is a risk of masking dilemma. Again, the use of insert earphones increases the MAX_MASK value. This is useful to obtain WRS at supra-threshold levels. For a 25 dB presentation level, using insert earphones for masking would increase MAX_MASK to 60 dB, yielding a range of 48 to 60 dB for allowed masking intensities.

Case 3. TE: mixed hearing loss; NTE: conductive hearing loss (Figure 3)

Need for masking
PL_TE ≥ BEST_AC_NTE
PL_TE ≥ 5 dB

For any presentation level equal to or greater than 5 dB, masking is required.

Minimum masking level
As the NTE has a conductive component, consideration of the occlusion effect is not required.
MIN_MASK = PL_TE + MAX_GAP_NTE
MIN_MASK = PL_TE + 30 dB

Maximum masking level
MAX_MASK = BEST_BC_TE + IA_AC – 5 dB
MAX_MASK = 40 + 40 dB – 5 dB = 75 dB

For a presentation level close to the SRT (assuming it is close to bone-conduction PTA) of 35 dB, the minimum masking level would be 65 dB. Under these conditions, a 70 dB masking level can be applied. For WRS at supra-threshold levels, a masking dilemma would likely occur. To avoid this, the use of insert earphones for masking is recommended. In that case, the maximum permissible masking level would be:

MAX_MASK = 40 + 60 dB – 5 dB = 95 dB

Case 4. Bilateral conductive hearing loss (Figure 4)

Need for masking
PL_TE ≥ BEST_BC_NTE
PL_TE ≥ 10 dB

Again, for any presentation level equal to or greater than 10 dB, masking is required.

Minimum masking level
MIN_MASK = PL_TE + MAX_GAP_NTE
MIN_MASK = PL_TE + 45 dB

Maximum masking level
MAX_MASK = BEST_BC_TE + IA_AC – 5 dB
MAX_MASK = 5 dB + 40 dB – 5 dB = 40 dB

This represents a masking dilemma, as the minimum masking level required exceeds the maximum permissible level. Yacullo [14] specifically analysed the case of speech recognition score determination in the context of a potential masking dilemma, indicating that the possible effects of overmasking in this type of test should be considered. Predictions about overmasking assume an interaural attenuation (IA) of 40 dB for speech with supra-aural headphones or 60 dB with insert earphones. It is imperative to remember that this is a highly conservative estimate, based on the lowest IA values reported in the literature. However, it is possible that the actual IA value for a given patient may be greater than this conservative estimate. If that is the case, the MAX_MASK would be higher, thus masking could be applied without the risk of overmasking. If the masker crosses over to the test ear, it is necessary to assess the effects that overmasking might have on the patient's performance. It is important to recall that the evaluation intended is speech recognition at supra-threshold presentation levels. Therefore, we must ask what effect the crossover of masking noise from the non-test ear (NTE) to the test ear (TE) might have on the patient's supra-threshold performance.

The presence of masking noise in the TE will reduce the signal-to-noise ratio (SNR) in that ear; as a result, the crossover of the masking noise may potentially reduce supra-threshold speech recognition ability. However, it is important to emphasise that the objective of supra-threshold discrimination testing is to estimate the maximum discrimination score, that is, the maximum percentage of recognition for phonetically balanced word lists. If the patient demonstrates normal word recognition ability (90–100%) in the presence of masking, there is no evidence of overmasking, since it did not affect the outcome. In that case, the goal of evaluating speech recognition at a supra-threshold level has been fully achieved. On the other hand, if the patient exhibits a reduced recognition score (below 90%), overmasking may have occurred. This non-optimal score may be due either to overmasking or to an actual reduction in speech recognition ability. Therefore, Yacullo [14] recommends advising on this possibility in the test report.

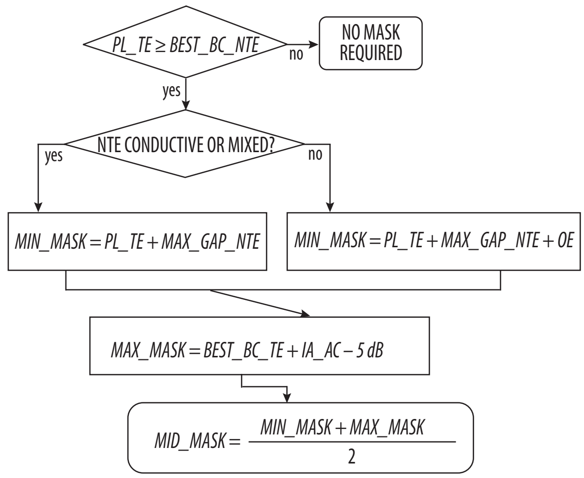


Figure 5. Flow diagram showing the complete procedure

Discussion

This article addresses the importance of using appropriate masking techniques when evaluating speech thresholds and word recognition scores via bone conduction. It is important to distinguish between pure-tone and speech masking procedures. In pure-tone audiometry, a psychoacoustic method such as the Plateau approach is generally considered appropriate. By contrast, speech audiometry – whether for speech recognition threshold (SRT) or word recognition score (WRS) determination – requires calculating the appropriate masking level for each presentation level. Consequently, speech masking is typically regarded as an acoustic method [13]. However, clinicians frequently overlook the inherently dynamic and broadband characteristics of speech stimuli, as well as the necessity of adopting a tailored methodological approach that accounts for the contribution of distinct frequency bands to speech recognition.

Given the limited literature on this subject, studying the issue requires a specific approach that considers the foundational principles of clinical masking theory. Since interaural attenuation for bone conduction is virtually negligible, masking is often needed. Additionally, the limitations inherent to this technique should be acknowledged, particularly the high likelihood of overmasking. As Floyd [17] has emphasised, the SRT results obtained through bone conduction should be interpreted with extreme caution. In cases 1 and 2, the absence or minimal air-bone gap in the non-test ear means that the minimum masking level required is approximately equal to the stimulus level presented to the TE plus the occlusion effect compensation. Cases 3 and 4 show scenarios with significant air-bone gaps in the non-test ear, requiring higher minimum masking levels and posing greater challenges, although compensation for the occlusion effect is not needed. In case 4, a bilateral conductive hearing loss, no corrections are required for the Lidén formulas, but it is strongly recommended to use insert phones for masking and the correct value of IA for this type of transducer (at least 60 dB).

When assessing the need for masking and determining appropriate masking levels for speech stimuli presented through bone conduction, applying Lidén's formulas facilitates the analysis of various cases. When dealing with bone-conducted speech stimuli, it is important to take into account the limitations imposed by the maximum output level of the audiometer, which constrain the ability to measure WRS at levels substantially above the SRT. Often, the application of high stimulus levels is restricted because the masking required to prevent cross-hearing would exceed the maximum permissible levels to avoid overmasking, leading to a masking dilemma. All the cases reviewed here demonstrate that the limited range of applicable masking levels yields a restricted range of test stimuli.

This finding strongly reinforces the recommendation to use insert earphones for masking of speech via bone conduction, as these transducers offer approximately 20 dB greater interaural attenuation compared to supra-aural headphones. This extra attenuation significantly broadens the effective range for both masking levels and test stimuli.

For evaluating potential surgical outcomes, pre- and postoperative assessments of SRT (or SDT) could serve as valid tools and are generally feasible when effective masking levels are appropriately applied. To obtain WRS at suprathreshold levels, it is crucial to verify the absence of overmasking. If possible, reporting WRS values at levels above the threshold is appropriate; however, if overmasking precludes this, the SRT may still provide a reliable alternative for predicting postoperative results. By considering preoperative air-conduction WRS values, one can estimate the anticipated postoperative discrimination outcomes. The perceptual characteristics of hearing loss, such as the rollover phenomenon, may be demonstrated through air-conduction speech audiometry without bone-conduction testing. To evaluate potential surgical outcomes, predicting the closure of the air-bone gap at the SRT level may be enough. This would indicate the expected dB HL at which the new air-conduction SRT might be found, assuming that the air-bone GAP is closed. The maximum discrimination score should remain unchanged, and a similar shift in dB in the stimulus level at which it occurs may be predicted.

Figure 5 presents a flow diagram that illustrates the complete procedure, including the criterion for determining whether masking is required and the specification of the minimum and maximum masking levels.

By systematically analysing common audiometric configurations, this approach provides a clinical tool that supports otologists and audiologists in minimising masking errors. Importantly, accurate masking has direct real-world implications: it enhances the reliability of cochlear reserve assessment, informs candidacy for stapedectomy, and improves the prediction of postoperative outcomes in otosclerosis and other middleear pathologies. In this way, the proposed framework seeks to bridge a critical methodological gap and expand the practical utility of boneconduction speech audiometry in everyday clinical practice.

Acknowledgement

The authors express their gratitude to Dr. Daniel Orfila for his continuous support and valuable contributions.

Funding

This research and article did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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