Masking Redux II: A Recommended Masking Protocol

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Abstract

This is the second in a series of two papers on masking. The objective of these papers is to develop a masking protocol that provides valid measures of threshold and is, in general, faster than the plateau method. In the first paper, a masking method was presented that can replace the traditional plateau method in most masking situations. This new method is optimized to require fewer masking levels than the plateau method. As a result, this optimized method is faster, sometimes significantly, than the plateau method. This paper evaluates the optimized method and compares the optimized method to the traditional plateau method. This paper identifies specific masking situations in which the optimized method is not appropriate. A variation on the plateau method is described. When combined with the optimized method, these two masking methods constitute a recommended masking protocol that can be used in all masking situations.

Key Words: Audiometry, auditory thresholds, masking, optimized method, plateau method

Abbreviations: A1 = initial masking level (air conduction) for the optimized method; ABG = air-bone gap; ABGN: = actual air-bone gap in the nontest ear; ABGT = actual air-bone gap in the test ear; AC = air conduction; AMR = adequate masking range; ATN = air-conduction threshold in the nontest ear; B1 = initial masking level (bone conduction) for the optimized method; BC = bone conduction; BTT = bone-conduction threshold of the test ear; IA = actual interaural attenuation; IM = initial masking level for the plateau method, either air- or bone-conduction testing; MIA = assumed minimum interaural attenuation; NTE = nontest ear; PWA = plateau width for air conduction; PWB = plateau width for bone conduction; TE = test ear

Sumario

Este es el segundo de una serie de dos trabajos relacionados con el enmascaramiento. El objetivo de estos trabajos es desarrollar un protocolo de enmascaramiento que proporcione mediciones válidas del umbral y que sea, en general, más rápido que el método del plateau. En el primer trabajo, se presentó un método de enmascaramiento que puede reemplazar al método tradicional del plateau en la mayor parte de las situaciones que lo requieren. Este nuevo método ha sido optimizado para necesitar menos niveles de enmascaramiento que el método del plateau. Como resultado, este método es significativamente más rápido que el tradicional. Este trabajo evalúa el método optimizado y lo compara con el método del plateau. El trabajo identifica situaciones específicas de enmascaramiento en las que el método optimizado no es apropiado. Se describe una variante del método del plateau. Cuando se combinan con el método optimizado, estos dos métodos consti-

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tuyen el protocolo recomendado de enmascaramiento, que puede ser utilizado en todas las situaciones que demandan enmascaramiento.

Palabras Clave: Audiometría, umbrales auditivos, enmascaramiento, método optimizado, método del plateau

Abreviaturas: A1 = nivel de enmascaramiento inicial (conducción aérea) para el método optimizado; ABG = brecha aéreo-ósea; ABGN = brecha aéreo-ósea real en el oído no evaluado; AC = conducción aérea; AMR = rango adecuado de enmascaramiento; ATN = umbral de conducción aérea en el oído no evaluado; B1 = nivel de enmascaramiento inicial (conducción ósea) para el método optimizado; BC = conducción ósea; BTT = umbral de conducción ósea en el oído evaluado; IA = atenuación interaural real; IM = nivel inicial de enmascaramiento para el método del plateau, tanto para evaluaciones por vía aérea u ósea; MIA = supuesta atenuación interaural mínima; NTE = oído no evaluado; PWA = ancho del plateau para la conducción aérea; PWB = ancho del plateau para la conducción ósea; TE = oído evaluado

This is the second and final paper in a series on masking. It is strongly recommended that the first paper be read prior to this paper. The purpose of these papers is to develop a masking protocol that yields valid measures of threshold and is sufficiently fast to be acceptable in most clinical environments. Hopefully, this protocol will discourage audiologists from using shortcut masking procedures because the plateau method is perceived as being too slow. In the first paper (Turner, 2003), an optimized masking method is described that should, in many masking situations, be significantly faster than the traditional plateau method. This paper has several objectives: (1) theoretically evaluate the validity of the optimized method for a variety of audiometric configurations; (2) compare the optimized method to the traditional plateau method; (3) determine any limitations on the use of the optimized method; (4) provide a recommended masking protocol that can be used in all masking situations.

MASKING METHODS

Plateau Method

The most common masking procedure is the plateau method. There are several variations on the plateau method. For this paper, the plateau method will be defined as the following:

1. Measure an unmasked air-conduction (AC) threshold for each ear and an unmasked bone-conduction (BC) threshold.
2. At each frequency, determine if masking is required using conventional criteria.
3. Set the initial masking level (IM) 10 dB above the AC threshold of the nontest ear (NTE) and reestablish threshold.
4. The masking level is increased 10 dB and threshold reestablished.
5. When the masking level is increased twice (20 dB range) with no change (poorer) in threshold, the masker is in the plateau, and the measured threshold is the actual threshold.

Optimized Method

The masking method developed in the first paper is as follows:

1. Measure an unmasked AC threshold for each ear and an unmasked BC threshold.
2. At each frequency, determine if masking is required using conventional criteria.
3. Set the initial masking level equal to the AC threshold of the test ear (TE) minus 10 dB and reestablish the threshold.
4. Determine the dB shift in threshold due to the masker.
5. Increase the masking level an amount equal to the threshold shift and reestablish threshold.
6. If threshold improves or does not shift, the masker is in the plateau and the actual threshold has been determined. If the threshold shifts, repeat steps 5 and 6.

MASKING AND FREQUENCY DIAGRAMS

Masking diagrams, which are described in detail in the first paper, can be used to illustrate the optimized method and the plateau method. Briefly, a masking diagram is a plot of masked threshold versus masking level at a particular frequency. An example for AC testing is shown in Figure 1. In this example, the plateau is clearly evident in the diagram, and both masking methods, optimized and plateau, have been implemented. The masking methods are represented by arrows on the masking diagram. The arrows indicate the masking levels specified by the particular method. The black arrows (A1–A3) are the optimized method, and the shaded arrows (IM and unlettered) are the plateau method.

To the left of the masking diagram is a frequency diagram. This diagram represents one frequency on the audiogram and displays a variety of information. To the left of the axis are unmasked, masked, and actual thresholds. (An explanation of the audiometric symbols used in this and other figures is given in Figure 2.) If the unmasked threshold is the actual threshold, then only the unmasked threshold is shown. To the right of the axis are arrows corresponding to the arrows in the masking diagram for the optimized method. For the plateau method, only the arrow corresponding to the initial masking level (IM) is shown on most frequency diagrams.

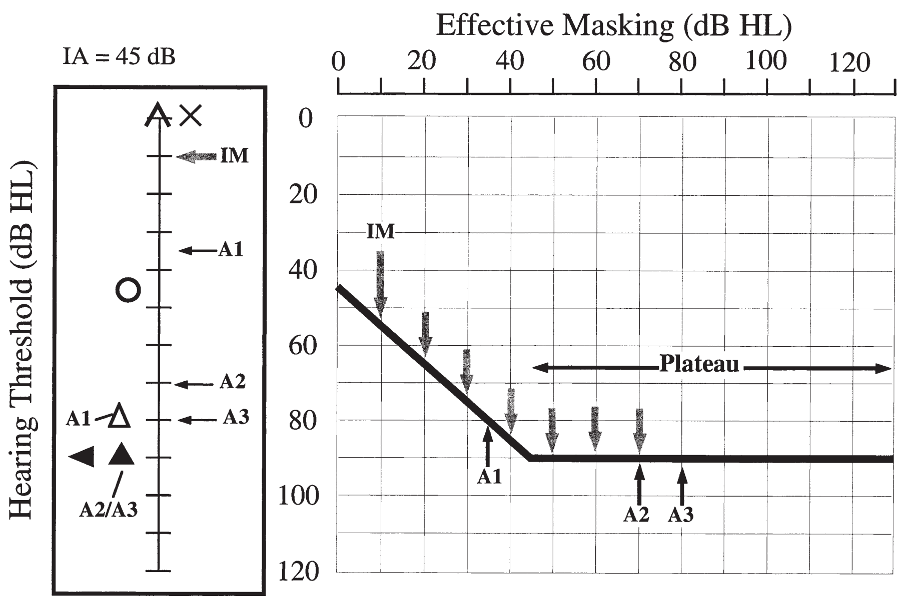

Figure 1. Masking and frequency diagrams for air-conduction testing of the right ear. The plateau method is represented by shaded arrows, the optimized method by black arrows. See Figure 2 for an explanation of the audiometric symbols. A1: initial masking level for the optimized method; A2, A3: additional masking levels for air-conduction testing using the optimized method. IA: actual interaural attenuation; IM: initial masking level for the plateau method.

AIR

	Unmasked	Masked	Actual
Right	○	△	▲
Left	×	□	■

BONE

	Unmasked	Masked	Actual
Right	Unspecified	[	◄
Left	as to ear	]	►

Figure 2. Explanation of the audiometric symbols used in other figures.

Based on the thresholds shown in Figure 1, it is evident that there is a severe, unilateral, sensorineural loss in the right ear. We are assuming a minimum interaural attenuation (MIA) equal to 40 dB. The MIA is the criterion used to determine if masking is required for AC thresholds. When the apparent ABG (air-bone gap) equals or exceeds the MIA, masking is needed. In all examples in this paper, the MIA will be 40 dB for AC testing, consistent with the use of supra-aural headphones. Supra-aural phones present a more difficult masking situation than insert phones and are a better test of a masking procedure. Masked BC thresholds are required when the apparent ABG exceeds 10 dB.

In this example, there is an apparent ABG in the right ear of 45 dB; therefore, masking is required for the AC and BC thresholds. The actual interaural attenuation (IA) is 45 dB. With the plateau method, the initial masking level (IM) would be 10 dB HL, 10 dB greater than the unmasked AC threshold of the NTE. The masking level would be increased in 10 dB steps until the plateau is defined by two increases in masking level with no change in threshold. This is shown by the shaded arrows in Figure 1.

With the optimized method, initial masking level (A1) is set at 35 dB HL, 10 dB less than the AC threshold of the TE. This masking level is 35 dB above the AC threshold of the NTE. Thus, we would expect a shift in masked threshold up to 35 dB. In this case, the right AC threshold shifts 35 dB from 45 dB HL to 80 dB HL. Because the threshold has shifted 35 dB, we increase the masking level by the same amount, 35 dB. This level (A2) produces a 10 dB shift in threshold. Because the threshold shifted 10 dB, the masking level is increased 10 dB (A3). The threshold remains the same confirming that the maskers A2 and A3 are in the plateau region.

PLATEAU WIDTH AND AMR

Plateau Width

Before evaluating the two masking procedures, it is worthwhile to review the issue of plateau width. With any masking procedure, accurate thresholds will be measured when the masking level is within the plateau region. Thus, the ability to place the masker within the plateau is related to the width of the plateau. This width can vary significantly depending upon several factors. Understanding the relationship between plateau width and audiogram configuration is important for anticipating masking difficulty and for selecting the appropriate masking procedure.

The equations for plateau width are easily derived from the equations of Liden et al (1959) for calculating minimum effective masking and maximum usable masking. The equations for plateau width are

$$PWA = 2IA - ABGT - ABGN \qquad (1)$$

$$PWB = IA - ABGN \qquad (2)$$

where PWA is plateau width for air-conduction testing, PWB is plateau width for bone-conduction testing, IA is the actual interaural attenuation, ABGT is the actual air-bone gap (ABG) in the TE, and ABGN is the actual air-bone gap in the NTE.

We can illustrate these equations using Figure 3. In the frequency diagram, it is evident that the unmasked AC threshold in the right ear (60 dB HL) is 50 dB greater than the unmasked BC threshold (10 dB HL). The unmasked AC threshold is not the actual threshold in the right ear and, therefore, must be due to crossover to the NTE. The IA must be 50 dB. If IA was less than 50 dB, the unmasked AC threshold would have occurred at a lower (better) level. The actual thresholds also indicate a 40 dB ABG in the right ear (90 dB HL minus 50 dB HL) and a 20 dB ABG in the left (30 dB HL minus 10 dB HL). Using Equation 1, we have

$$PWA = 2IA - ABGT - ABGN =$$
$$100 - 40 - 20 = 40 \text{ dB}$$

This value, 40 dB, agrees with the plateau width in the masking diagram. We can use Equation 2 to calculate plateau width for BC testing.

$$PWB = IA - ABGN = 50 - 20 = 30 \text{ dB}$$

This agrees with the BC plateau width in the masking diagram.

These equations are not particularly useful when measuring thresholds because the thresholds that you are trying to measure must be known to evaluate the equations. The equations do, however, provide useful insight into plateau width. With AC testing, the plateau width can be as great as twice the IA and can easily exceed 100 dB. Plateau width is reduced by conductive loss in either ear. Plateau width for BC testing is generally smaller than for AC testing with a maximum width equal to the IA. This width is reduced by conductive loss in the NTE; conductive loss in the TE has no effect. As we will see, plateau width for AC and BC testing can be reduced

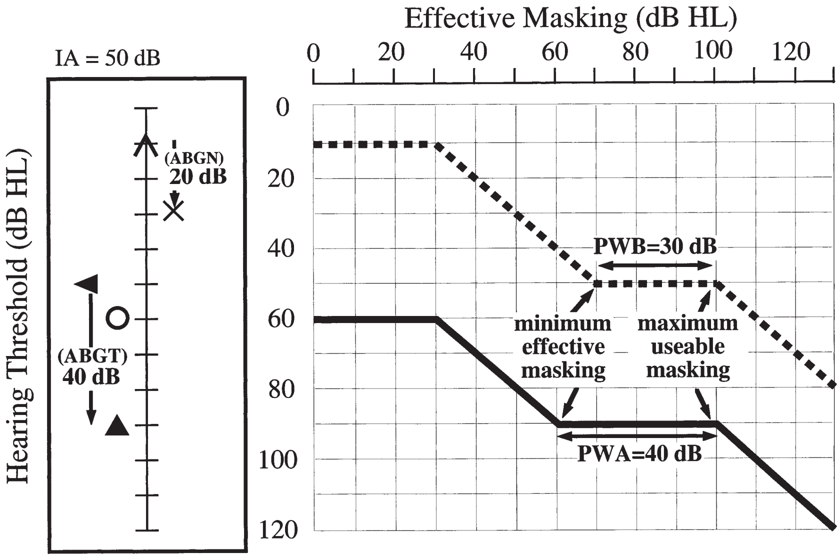

Figure 3. Masking and frequency diagrams illustrating plateau width for air-conduction testing (PWA) and bone-conduction testing (PWB). See Figure 2 for an explanation of the audiometric symbols. ABGN: actual air-bone gap in the non-test ear. ABGT: actual air-bone gap in the test ear. IA: actual interaural attenuation.

to zero for certain conditions, producing the classic masking dilemma.

With BC testing in the low frequencies, it may be necessary to correct for the occlusion effect. This is an increase in bone-conducted sound in the NTE because the ear is occluded. When required, the initial masking level is increased by an amount that depends on the frequency of testing, the type of headphone, and the amount of conductive loss in the NTE. Also, the occlusion effect will increase the minimum effective masking level, that is, the minimum masking required to reach the plateau. At first glance, this would indicate that the occlusion effect would decrease plateau width. In fact, data suggest that the maximum useable masking level will increase an equal amount and that plateau width would be relatively unchanged. (See Yacullo, 1996, 65, for a more detailed explanation.)

Adequate Masking Range

Technically, the masking plateau only occurs when the unmasked threshold in the TE is not the actual threshold but results from crossover to the NTE. If the unmasked threshold is the actual threshold, then there will be no plateau. For all masking levels up to overmasking, the threshold will remain at the actual threshold; there will be no region of undermasking to help define a plateau. We can define, however, an adequate masking range (AMR) that is somewhat analogous to the plateau. This is the range of masking levels from the minimum masking needed to mask the NTE to the maximum useable masking before overmasking. When the masking level is in this range, we know that the NTE is masked and is not responding to the tone. Minimum masking for the AMR is not the same as the minimum effective masking level for the plateau. For this paper, minimum masking is equal to the initial masking level, IM, as defined by Martin (1974). That is, the AC threshold of the NTE plus 10 dB.

Interestingly, the AMR for AC testing equals that for BC testing and is given by the following equation:

$$\text{AMR} = \text{IA} + \text{BTT} - \text{ATN} - 10\text{ dB} \qquad (3)$$

where BTT is the actual BC threshold in the TE and ATN is the actual AC threshold in the NTE. Figure 4 shows a masking diagram for a situation where the unmasked AC threshold in the right ear is the actual threshold. In this example we assume that IA = 50 dB. Applying Equation 3 we have

$$\text{AMR} = \text{IA} + \text{BTT} - \text{ATN} - 10\text{ dB} =$$
$$50 + 10 - 20 - 10 = 30\text{ dB}$$

The value of 30 dB agrees with the AMR indicated in the masking diagram.

UNMASKED THRESHOLD PATTERNS

The decision to mask and the decision as to masking procedure are based on the configuration of the unmasked thresholds. It is useful to divide the unmasked configurations into four patterns. In all patterns, the TE is the "poorer ear." That is, the unmasked AC threshold of the TE is

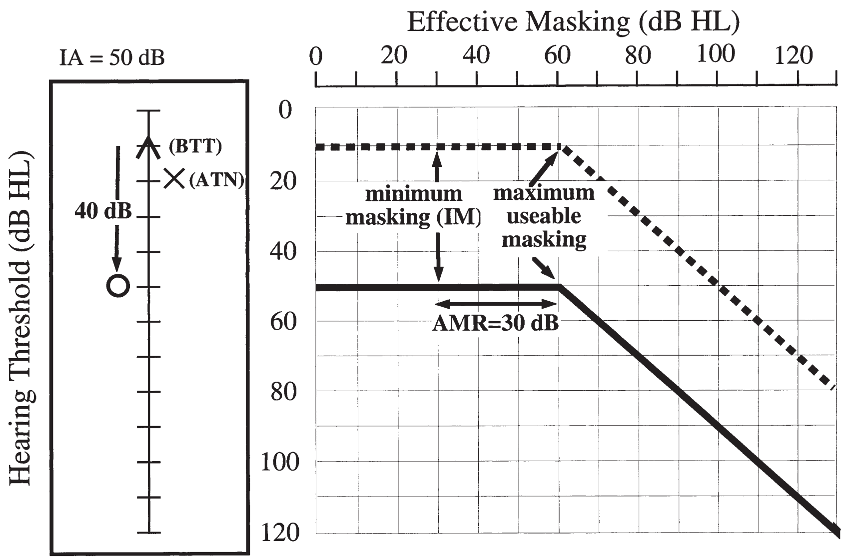

Figure 4. Masking and frequency diagrams illustrating adequate masking range (AMR). See Figure 2 for an explanation of the audiometric symbols. ATN: air-conduction threshold in the nontest ear. BTT: bone-conduction threshold of the test ear. IA: actual interaural attenuation.

equal to, or poorer than, the unmasked AC threshold of the NTE. The poorer ear would be tested first for masked thresholds.

The first pattern (Figure 5a) is called "unilateral" because the unmasked thresholds indicate the possibility of a unilateral conductive loss; that is, there is an apparent ABG in the TE. The actual loss could be conductive with the actual ABG equal to the apparent ABG, mixed with an actual ABG smaller than the apparent ABG, or sensorineural, in which case there would be no actual ABG. Note, the unmasked BC threshold does not have to lie in the normal range. It is the relationship between the two unmasked AC thresholds and the single unspecified (as to ear) unmasked BC threshold that is important, not the absolute levels. For this pattern, the apparent ABG in the TE must be sufficient to require masking. That is, the apparent ABG must equal or exceed the MIA. In the NTE, the apparent ABG must be 10 dB or less.

The second pattern (Figure 5b) is called "bilateral" because of the possibility of bilateral conductive loss. Only one ear must have conductive loss; the other could be conductive, sensorineural, or mixed. In the TE, the apparent ABG must be sufficient to require masking. In the NTE, the AC threshold must be, by definition, at least 25 dB better than the AC threshold of the TE.

The third pattern (Figure 5c) is called "symmetrical" because of the possibility of symmetrical bilateral conductive loss. Only one ear must have conductive loss; the other could be conductive, sensorineural, or mixed. In the TE, the apparent ABG must be sufficient to require masking for the AC threshold. By definition, the difference in unmasked AC thresholds must be 20 dB or less. In this pattern, there is a significant possibility of overmasking.

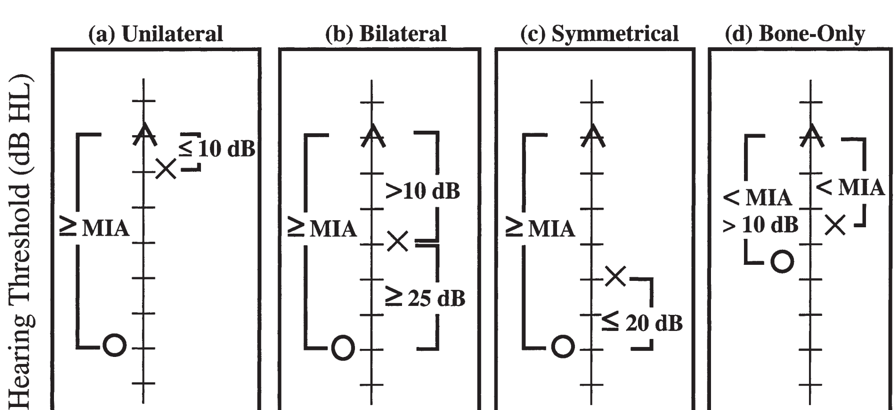

Figure 5. Four basic patterns for unmasked threshold configurations. See Figure 2 for an explanation of the audiometric symbols. MIA: assumed minimum interaural attenuation.

The fourth pattern (Figure 5d) is called "bone-only" because only the BC thresholds in one or both ears require masking. There is no need to mask AC thresholds because the apparent ABG is less than the MIA in both ears. If the apparent ABG is greater than 10 dB, masking is required for BC. An apparent ABG of 5 or 10 dB would not be masked because the ABG could be closed with masking due to test variability and central masking.

EVALUATION OF MASKING METHODS

The plateau and optimized masking methods were evaluated using masking diagrams for different threshold configurations that were derived from the unilateral, bilateral, symmetrical, and bone-only patterns. Obviously, a large number of actual audiometric configurations can be derived from any one pattern. Only a representative sample will be shown in this paper. Additional configurations have been evaluated but are not shown.

In all diagrams in this paper, the right ear will be the TE and the left the NTE. The evaluation of the procedures will be based on two questions: (1) For a particular threshold configuration, does the masking procedure place the last masking level (arrow) within the plateau and, thus, yield the valid threshold? (2) For a particular threshold configuration, which procedure requires the fewest masking levels (arrows) to identify the plateau? The two procedures will be evaluated for the four threshold patterns.

Unilateral Pattern

Consider the "best case" situation in Figure 6. The hearing loss in the TE is entirely sensorineural which results in the largest plateau or AMR. Only conductive loss diminishes plateau width. In fact, plateau width is 100 dB and 50 dB, respectively. In the unilateral pattern, the initial masking level (A1) for the optimized method is significantly greater than that (IM) for the plateau method. In this example, A1 is 40 dB above the unmasked AC threshold of the NTE. Thus, we would expect a shift in masked threshold up to 40 dB. In this case, threshold shifts 20 dB from 50 dB HL to 70 dB HL. The actual threshold shift (20 dB) is much less than the maximum possible shift (40 dB), providing strong evidence that the initial masking level (A1) is well into the plateau. Following the optimized method, the masking level is increased 20 dB (the amount of threshold shift) to 60 dB (A2). The threshold remains the same confirming the

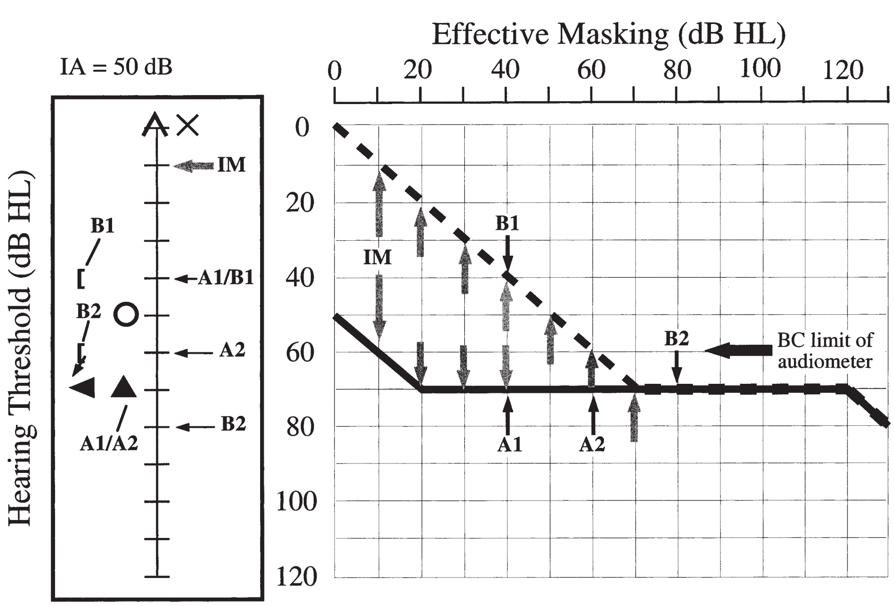

Figure 6. Masking and frequency diagrams for a best case unilateral pattern. Test ear has sensorineural loss. Note that the optimized method requires fewer masking levels than the plateau method. See Figure 2 for an explanation of the audiometric symbols. A1: initial masking level for air-conduction testing using the optimized method; A2, A3: additional masking levels for air-conduction testing using the optimized method. B1: initial masking level for bone-conduction testing using the optimized method; B2: additional masking level for bone-conduction testing using the optimized method. IA: actual interaural attenuation. IM: initial masking level for the plateau method, either air- or bone-conduction testing.

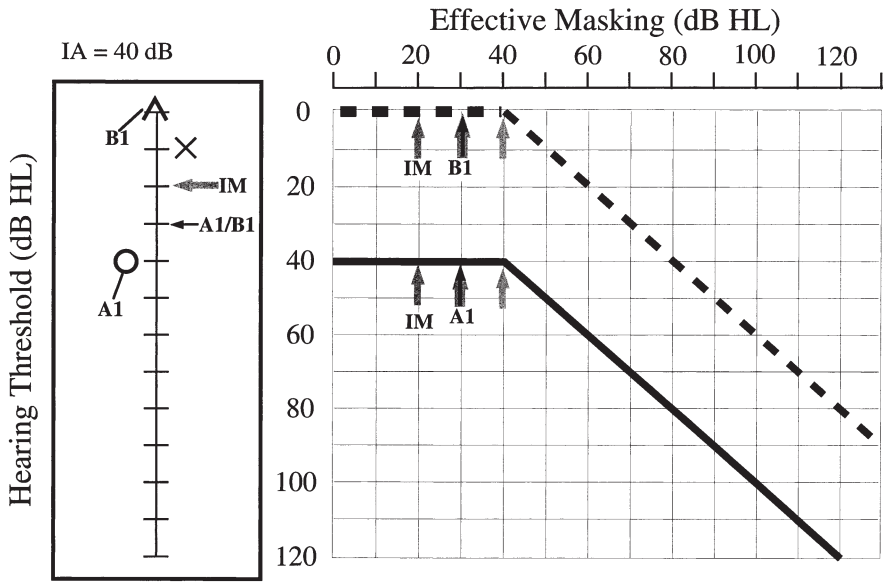

Figure 7. Masking and frequency diagrams for a "worst case" unilateral pattern. Test ear has conductive loss, and actual air-bone gap equals the actual interaural attenuation (40 dB). See Figure 2 for an explanation of the audiometric symbols. A1: initial masking level for air-conduction testing using the optimized method. B1: Initial masking level for bone-conduction testing using the optimized method. IA: actual interaural attenuation. IM: initial masking level for the plateau method, either air- or bone-conduction testing.

plateau. Thus, the optimized method requires two masking levels to identify plateau and yield the actual threshold. In contrast, the plateau method requires four masking levels. The difference between the procedures is more dramatic for BC testing. For this example, and all future examples, we will assume that the BC limit for the audiometer is 60 dB HL, as indicated in Figure 6. The optimized method requires two masking levels to move threshold beyond the limit of the audiometer, whereas the plateau method requires eight levels.

For any unmasked threshold pattern, we can define a "worst case" situation that would yield the minimum plateau width or AMR. For this to occur, the IA must equal the MIA, for example, 40 dB for supra-aural phones. The apparent ABG in the unmasked thresholds for the TE must represent the actual ABG, and that ABG must be maximum conductive, that is, the ABG equals the IA. It should be recognized that an ABG cannot exceed the IA. With this worst case, any apparent ABG in the unmasked thresholds for the NTE must be the actual ABG in that ear. While this situation would rarely occur, it represents the most difficult masking situation. We can use the equations presented earlier to calculate the worst case plateau width and AMR. For the unilateral pattern, the minimum plateau width is 30 dB and the minimum AMR is 20 dB.

A worst case situation for the unilateral pattern is shown in Figure 7. We assume IA equals 40 dB, the ABG in the TE is maximum conductive (40 dB), and there is a 10 dB ABG in the NTE. In this situation, there is no plateau, but there is an AMR. As stated above, the AMR equals 20 dB.

With the plateau method, three masking levels would be required for both AC and BC testing. With the recommended method, only one level (A1, B1) is theoretically required. B1 is the initial masking level specified by the optimized method for BC testing. Both A1 and B1 would be 20 dB above the unmasked AC threshold in the NTE and should be sufficient to mask any crossover to the NTE. If there is no change in threshold, then the unmasked threshold is the actual threshold. If desired, it is generally acceptable to use an additional masker, 5 dB to 10 dB greater, to confirm the plateau. In this example, there should be no change in threshold with A1 or B1. If the threshold should shift (poorer) 5 to 10 dB because of test variability and/or central masking, the masking level can be increased an equal amount. There should be no further change (poorer) in threshold confirming the AMR.

Another interesting threshold configuration is the "Dead" ear (Figure 8). There is no plateau for AC or BC testing. The thresholds must be raised to the limits of the audiometer. The optimized method offers a significant advantage over the plateau method. As shown in the figure, the optimized method requires two masking levels to raise the AC and BC thresholds beyond audiometric limits, 60 dB for BC testing and 120 dB for AC testing. The plateau method

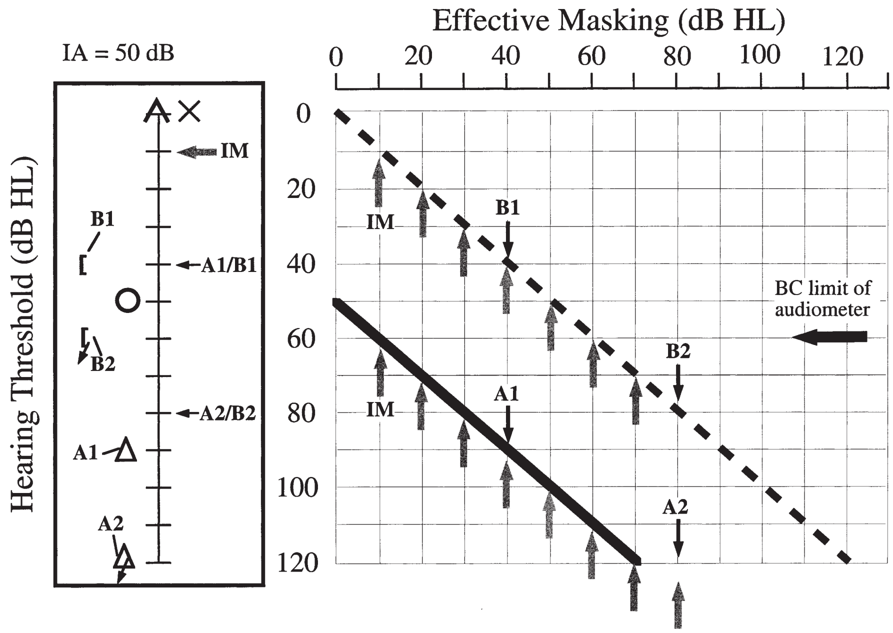

Figure 8. Masking and frequency diagrams for a unilateral pattern with a "Dead" test ear. Note that there is no plateau or adequate masking range. See Figure 2 for an explanation of the audiometric symbols. A1: initial masking level for air-conduction testing using the optimized method; A2: additional masking level for air-conduction testing using the optimized method. B1: initial masking level for bone-conduction testing using the optimized method; B2: additional masking level for bone-conduction testing using the optimized method. IA: actual interaural attenuation. IM: initial masking level for the plateau method, either air- or bone-conduction testing.

requires seven levels for AC testing and eight for BC testing.

The final threshold configuration for the unilateral pattern is shown in Figure 9. In this example, the TE has a mixed loss. The ABG in the TE reduces AC and BC plateau width (compare to Figure 6). The optimized method requires two masking levels to identify the AC and BC plateaus. The plateau method requires four levels for AC testing and six for BC testing.

With the unilateral pattern, plateau width and the AMR are relatively large even for the worst case threshold configuration. Both masking procedures placed the last masker in the plateau, or AMR, and identified the correct threshold. For all configurations, the optimized method required fewer masking

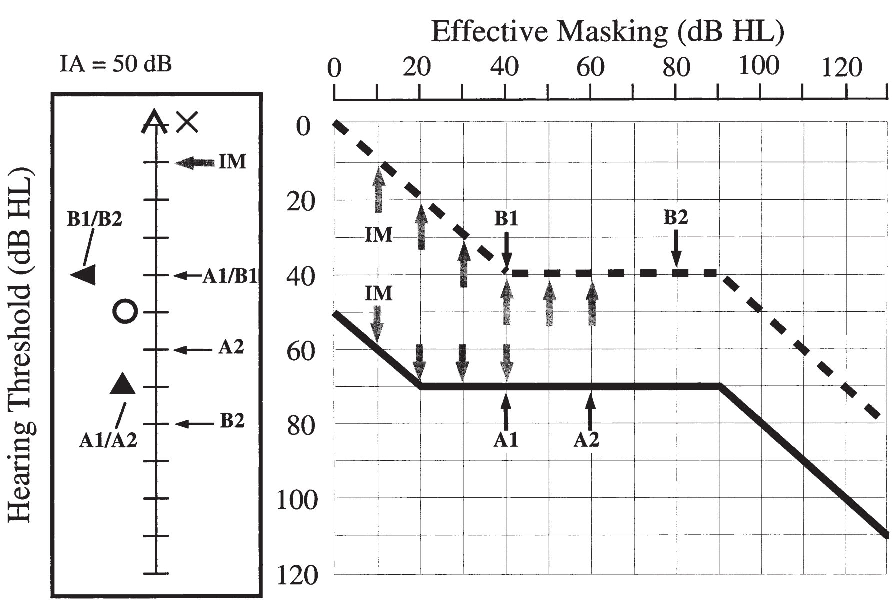

Figure 9. Masking and frequency diagrams for a unilateral pattern with a mixed hearing loss in the test ear. See Figure 2 for an explanation of the audiometric symbols. A1: initial masking level for air-conduction testing using the optimized method; A2: additional masking level for air-conduction testing using the optimized method. B1: initial masking level for bone-conduction testing using the optimized method; B2: additional masking level for bone-conduction testing using the optimized method. IA: actual interaural attenuation. IM: initial masking level for the plateau method, either air- or bone-conduction testing.

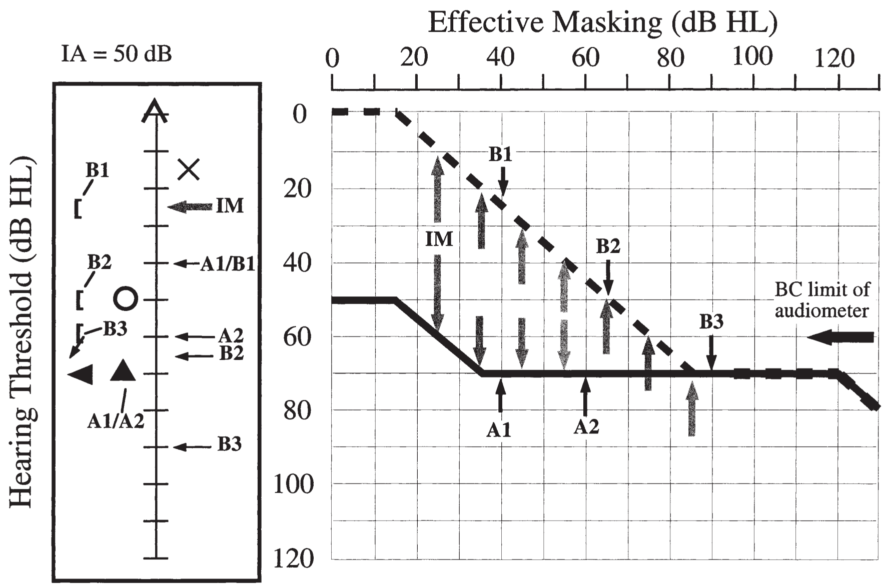

Figure 10. Masking and frequency diagrams for a "best case" bilateral pattern. Test ear has sensorineural loss; nontest ear has conductive loss. See Figure 2 for an explanation of the audiometric symbols. A1: initial masking level for air-conduction testing using the optimized method; A2: additional masking level for air-conduction testing using the optimized method. B1: initial masking level for bone-conduction testing using the optimized method; B2, B3: additional masking levels for bone-conduction testing using the optimized method. IA: actual interaural attenuation. IM: initial masking level for the plateau method, either air- or bone-conduction testing.

levels than the plateau method, significantly fewer for some threshold configurations.

Bilateral Pattern

A best case configuration for this pattern is shown in Figure 10. In this example, there is sensorineural loss in the TE and an ABG in the NTE. The ABG in the NTE will diminish plateau width for both AC and BC testing. Still, both procedures correctly identify the plateau for AC and elevate the threshold beyond audiometric limit for BC. The optimized method requires about half as many masking levels as the plateau method.

The worst case with a bilateral pattern would require that both ears have conductive loss. The ABG in the TE is maximum conductive and equals the IA. The difference between AC thresholds is 25 dB, the minimum permitted for this pattern. The

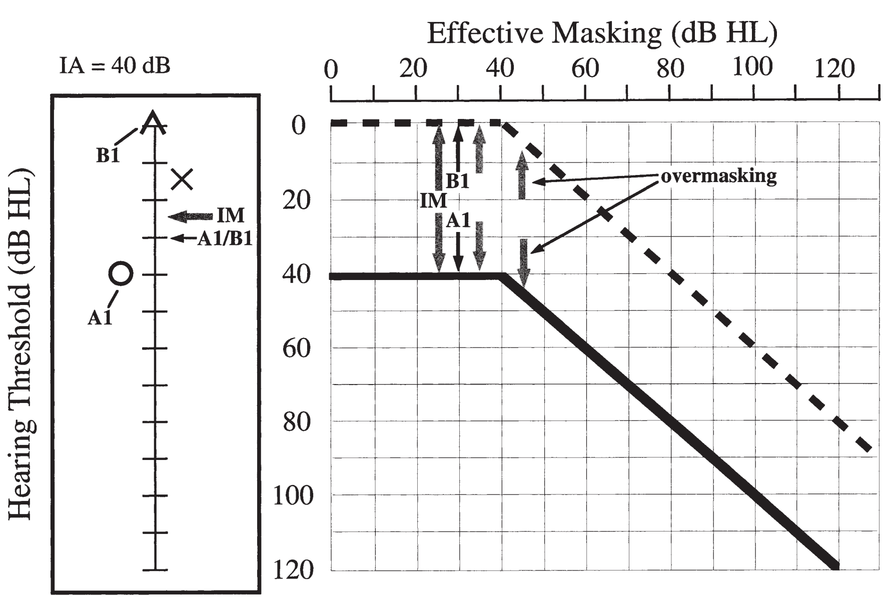

Figure 11. Masking and frequency diagrams for a "worst case" bilateral pattern. Both ears have conductive loss. Note that last masker for the plateau method, both air- and bone-conduction testing, is beyond the plateau and would result in overmasking. See Figure 2 for an explanation of the audiometric symbols. A1: initial masking level for air-conduction testing using the optimized method. B1: initial masking level for bone-conduction testing using the optimized method. IA: actual interaural attenuation. IM: initial masking level for the plateau method, either air- or bone-conduction testing.

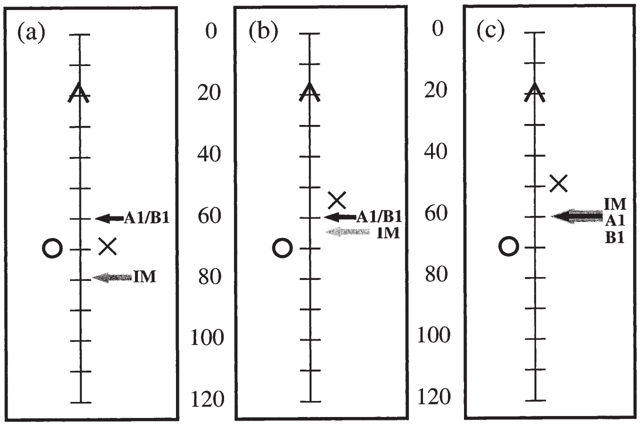

Figure 12. Possible unmasked threshold configurations for the symmetrical pattern. For differences in unmasked air-conduction thresholds less than 20 dB, the initial masking level for the optimized method (A1, B1) is inadequate. Only when the difference is 20 dB does it equal the initial masking level for the plateau method (IM). See Figure 2 for an explanation of the audiometric symbols. IA: actual interaural attenuation.

calculated minimum plateau width is 25 dB, and the AMR is 15 dB.

A worst case configuration is shown in Figure 11. Note that the initial masking level for the optimized method (A1, B1) is only 5 dB greater than for the plateau method (IM). Theoretically, only one masking level should be required with the optimized method. The initial masking level (A1, B1) is 15 dB above the unmasked AC threshold of the NTE and should be sufficient to mask the NTE. As discussed above, an additional masker could be used to confirm the plateau. With the bilateral pattern, it would be best to use a 5 dB masker increase. In addition, a second level may be needed if threshold shifts due to test variability or central masking. By our definition, the plateau method requires three levels, 10 dB apart, to establish plateau or AMR. In this example, the third masking level for the plateau method would result in overmasking.

With the bilateral pattern, plateau width and AMR tend to be smaller than in the unilateral pattern because of a possible conductive loss in the NTE. Even so, the optimized method correctly identifies the plateau and should yield valid measures of threshold. Consistently, the optimized method required fewer masking levels than the plateau method, but the advantage is not as great as with the unilateral pattern. The success of the plateau method depends on the particular definition. As shown in Figure 11, if the masking level must be increased twice in 10 dB increments to identify the plateau or AMR, then overmasking can occur in some threshold configurations. The masking levels may pass through the plateau into overmasking. This is not a fatal flaw but could result in some confusion.

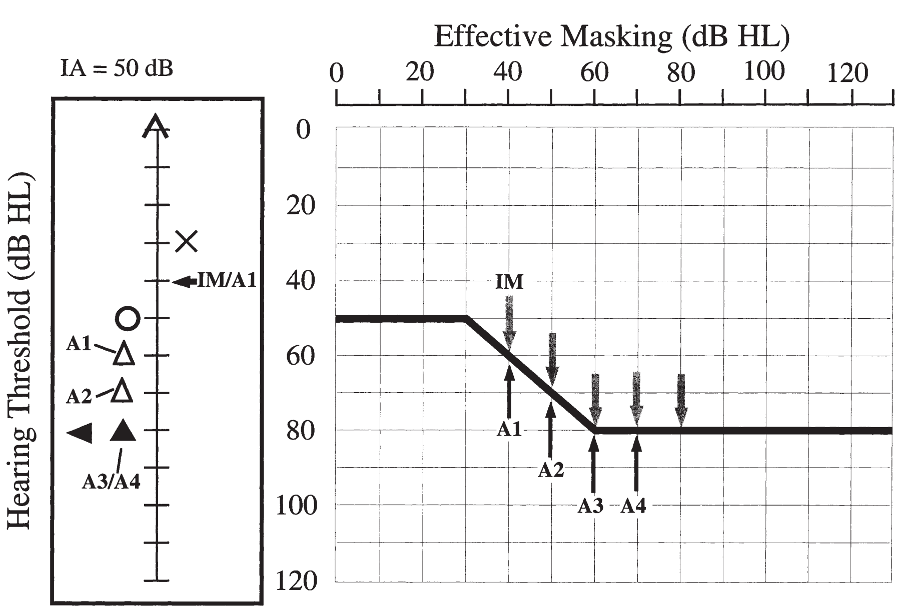

Figure 13. Masking and frequency diagrams for a symmetrical pattern when unmasked air-conduction thresholds are 20 dB apart. Initial masking level for both methods would be the same level. The optimized method essentially becomes the plateau method in this situation. See Figure 2 for an explanation of the audiometric symbols. A1: initial masking level for air-conduction testing using the optimized method; A2, A3, A4: additional masking level for air-conduction testing using the optimized method. IA: actual interaural attenuation. IM: initial masking level for the plateau method.

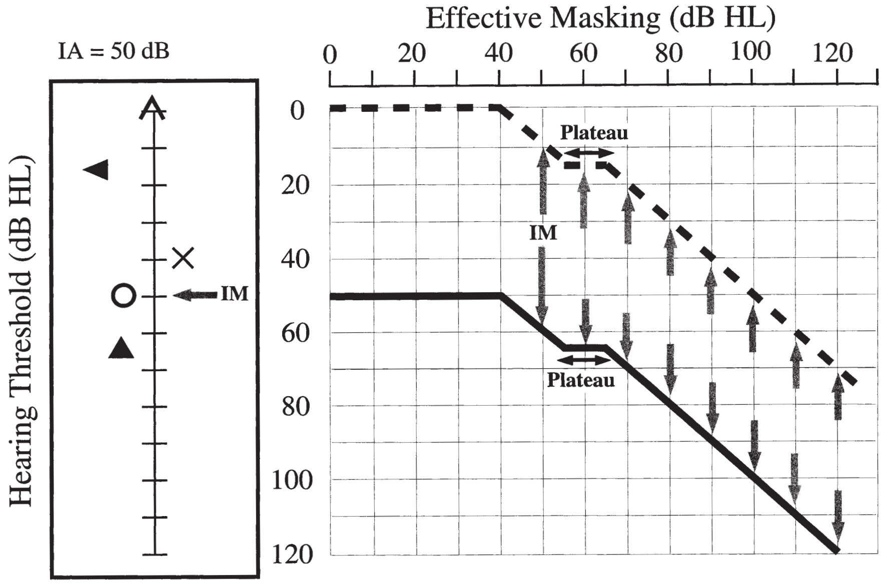

Figure 14. Masking and frequency diagrams for a symmetrical pattern when plateau width is only 10 dB. With 10 dB masker steps, the masking levels for the plateau method can fail to clearly identify the plateau. See Figure 2 for an explanation of the audiometric symbols. IA: actual interaural attenuation. IM: initial masking level for the plateau method.

Symmetrical Pattern

With the symmetrical pattern, the difference in unmasked AC thresholds must be less than 25 dB. Figure 12 shows three unmasked patterns that meet the definition of a symmetrical pattern. In Figure 12a, the unmasked AC thresholds are equal (70 dB HL). The optimized method would specify an initial masking level (A1, B1) at 60 dB HL. This is below the threshold of the NTE and obviously would not mask the NTE. The optimized method could not be used. The plateau method specifies an initial masking level (IM) of 80 dB HL. This level should mask the NTE, although overmasking is a possibility. In Figure 12b, the unmasked AC thresholds differ by 15 dB. The initial masking level (A1, B1) is only 5 dB above the level of the unmasked AC threshold of the NTE. We could not be certain that this level would provide adequate masking. Again, the optimized method should not be used. Thus, as the difference between unmasked AC thresholds varies from 0 dB to 15 dB, the initial masking level (A1, B1) of the optimized method may not be sufficient to ensure adequate masking. An initial masking level of at least 10 dB above the unmasked AC

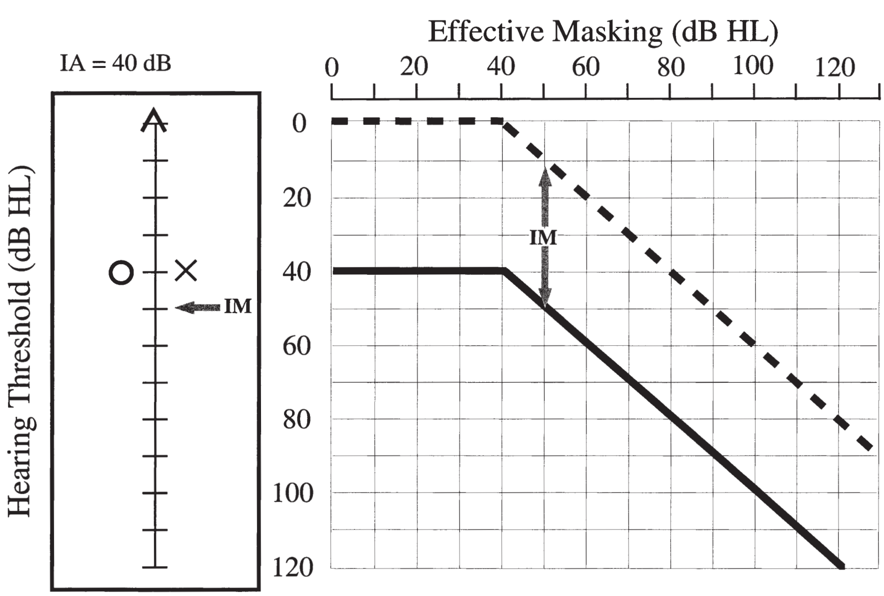

Figure 15. Masking and frequency diagrams for the classic masking dilemma. Hearing loss is bilateral conductive, and the air-bone gaps (40 dB) equal the actual interaural attenuation (IA). There is no plateau or adequate masking range so that even the initial masking level (IM) causes overmasking. See Figure 2 for an explanation of the audiometric symbols.

threshold of the NTE, as specified by the plateau method, should be used.

In Figure 12c, the unmasked AC thresholds differ by 20 dB, the maximum for the symmetrical pattern. In this case, the initial masking level (A1) for the optimized method is at the same level (60 dB HL) as the initial masking level (IM) for the plateau method. When this occurs, the optimized method essentially becomes the plateau method. Both procedures use the same initial masking level and would theoretically increase the masking level in 10 dB steps. This is illustrated by the example in Figure 13. Note that the masking levels are the same for both masking methods, although the optimized method may theoretically require one fewer masking level.

These results suggest that for a symmetrical pattern the optimized method should not be used but that the plateau method may be an acceptable masking procedure. However, the plateau method as defined for this paper may not always be appropriate. In particular, the use of 10 dB masker steps may not be adequate to define a small plateau or AMR. This limitation is illustrated in Figure 14, where the 10 dB steps cause the masker to pass through the plateau without the plateau being evident. A better solution would be to use the plateau method with 5 dB steps. The small step size provides the resolution needed to define a small plateau or AMR.

With a symmetrical pattern, there is the potential for the plateau or AMR to be quite small. That is the basis for recommending a 5 dB masker step. Just because the plateau can be small, however, does not mean that it has to be small. If the IA is much larger than the actual ABGs, then the plateau or AMR could be of reasonable size. In this situation, using a 5 dB step would be inefficient. A reasonable option would be to test with the more traditional 10 dB step. In many situations, this may be sufficient to identify the plateau and, thus, save time relative to the use of 5 dB steps. If no plateau is identified with 10 dB steps, then it is necessary to retest with 5 dB steps.

Consider the worst case situation shown in Figure 15. Both ears have maximum conductive loss; that is, the actual ABG in both ears equals the MIA. In this situation, there is no plateau or AMR. This is the classic masking dilemma. The initial masker (IM) will overmask and even using the plateau method with 5 dB masker steps will not identify a plateau. However, masking should always be attempted with the symmetrical pattern even if the unmasked thresholds suggest the possibility of a masking dilemma. If the IA is greater than the MIA, it may be possible to define a plateau or AMR, as in Figure 16. In this example, the IA is 20 dB greater than the MIA, resulting in an AMR of 10 dB. This could be identified using 5 dB masker steps.

Bone-Only Pattern

In this pattern, masking is required only for BC thresholds, never for AC thresholds for either ear. The strategy developed for the other patterns will work for this pattern. If the AC thresholds differ by more than 20

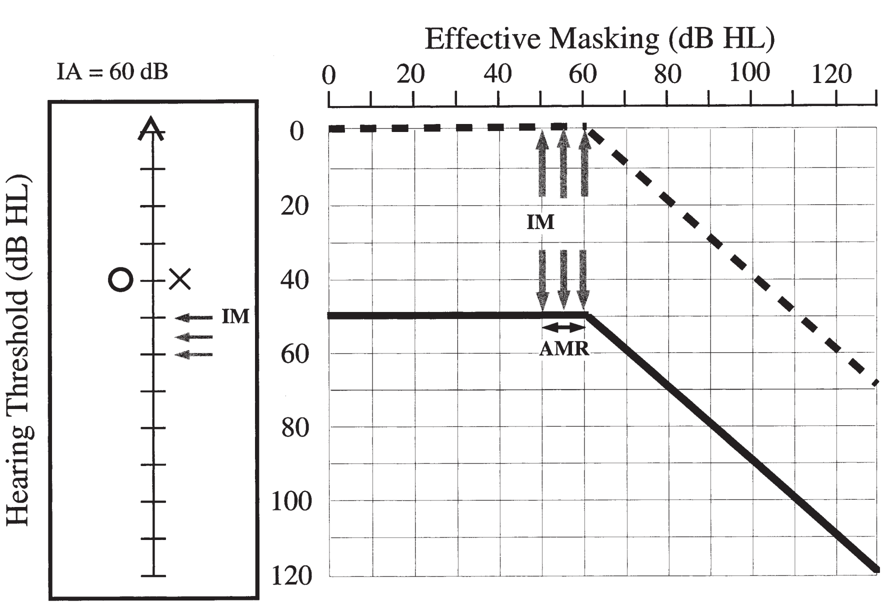

Figure 16. Masking and frequency diagrams for a symmetrical pattern that appears to be a masking dilemma, but is not. The air-bone gaps (40 dB) are less than the actual interaural attenuation (60 dB). There is a small adequate masking range (AMR) that can be identified using 5 dB masker steps. See Figure 2 for an explanation of the audiometric symbols. IA: actual interaural attenuation. IM: initial masking level for the plateau method, either air- or bone-conduction testing.

dB, the optimized method should be used. Otherwise, use the plateau method with 5 or 10 dB steps, as discussed above. In this pattern, masking is required only for BC thresholds because the apparent ABG in both ears is less than the MIA. This means that the apparent ABG will always be smaller than the IA. The plateau or AMR for this pattern will tend to be larger than for the symmetrical pattern, so there may be more success using 10 dB masker steps.

RELATED ISSUES

Reestablishing Threshold

Both the plateau method and the optimized method require that thresholds be reestablished. As discussed in the first paper, there are two techniques that can be used. The traditional procedure is the up-down search for threshold. An alternate strategy is the "single-tone" procedure in which the tone is presented once at each masking level. If there is a response to the tone, the tone is considered to be at threshold at that masking level, and the masking level is increased. If there is no response, then the tone is increased in 5 or 10 dB steps and presented once at each level until there is a response. This response indicates the threshold at that masking level. If this single-tone procedure is used to reestablish threshold and identify the plateau, then the threshold in the plateau, which is the actual threshold of the ear, should be measured using the more accurate up-down procedure.

High Masking Levels

There is one caution when using the optimized method. In certain situations, the method can specify a masking level that is extremely high. An example is shown in Figure 17. The left ear is normal, and the right ear has a profound sensorineural loss. The second masker (A2) is in the plateau, but the method specifies a third masker (A3) at 105 dB HL to confirm the plateau. It would be undesirable to subject a normal ear to this level of masking, and it is not necessary to identify the plateau. Once a relatively high level is reached, for example, greater than 80 dB HL, it would be better to increase the masker in smaller steps of 5 dB or 10 dB (A3') until the plateau is identified or the masked threshold reaches the limit of the audiometer.

A more likely situation is shown in Figure 18 for BC testing. The left ear is normal, and the right ear has a moderate sensorineural loss. It has been determined that the right unmasked AC threshold is the actual threshold. A masked BC threshold is required because the apparent ABG is greater than 10 dB. The initial masking level (B1) elevates the threshold, but the plateau has not been identified. The method specifies a second

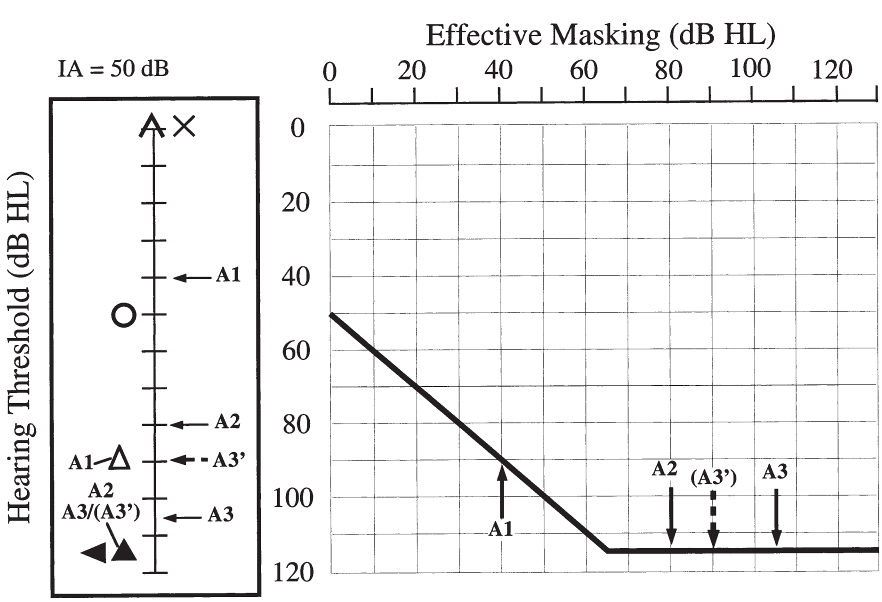

Figure 17. Masking and frequency diagrams for a situation where the optimized method specifies a high masking level (A3) in a normal ear. The plateau can be identified using smaller steps, for example, 5 dB to 10 dB, as illustrated by the dashed arrow (A3'). See Figure 2 for an explanation of the audiometric symbols. A1: initial masking level for air-conduction testing using the optimized method; A2, A3: additional masking levels for air-conduction testing using the optimized method. IA: actual interaural attenuation.

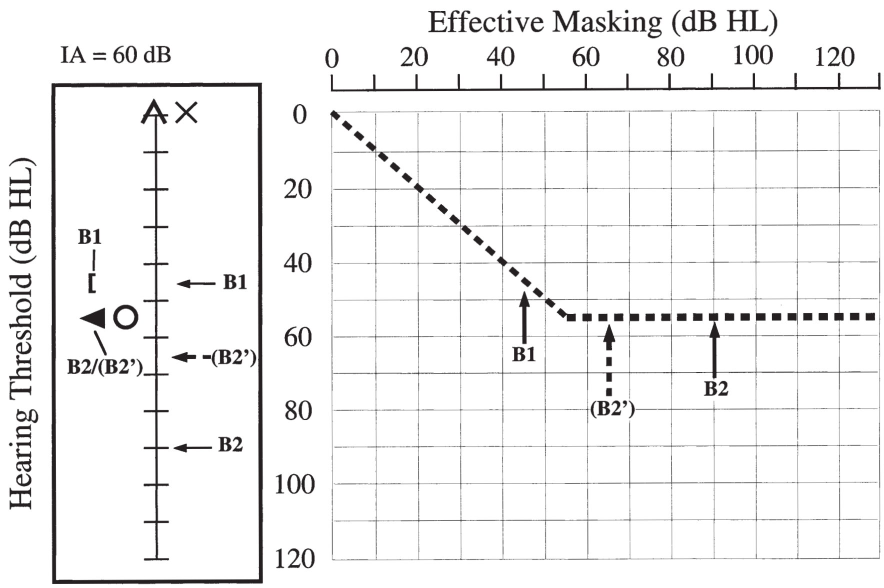

Figure 18. Masking and frequency diagrams for a situation where the optimized method specifies a high masking level (B2) in a normal ear. The bone-conduction threshold need only be raised to the air-conduction threshold. A smaller masking level can be used (B2'). See Figure 2 for an explanation of the audiometric symbols. B1: initial masking level for bone-conduction testing using the optimized method; B2: additional masking level for bone-conduction testing using the optimized method. IA: actual interaural attenuation.

masker at 90 dB HL (B2). This level could be uncomfortable to a normal ear and is unnecessary. A smaller masking level increase (B2'), 20 dB in this case, would be adequate to raise the masked threshold to the AC threshold, which is sufficient since BC thresholds should not, in theory, be poorer than AC thresholds. In this example, had the actual AC and BC thresholds been poorer, for example, 80 dB HL, it would only be necessary to demonstrate no BC response at the BC limit of the audiometer. Again a smaller masking level increase could be used.

Masked Thresholds in the Better Ear

The four patterns used to evaluate the two masking methods all assume that the TE is the poorer ear. For AC testing, it is seldom necessary to obtain masked thresholds in the better ear. The only possible exception occurs with the Symmetrical Pattern when the unmasked AC thresholds are similar, and it is difficult to be certain as to which ear is actually the poorer ear. In this situation, it may be necessary to test both ears. With BC testing, testing the better ear is more common, particularly with the bone-only pattern. If it is necessary to measure masked thresholds in the better ear, then which masking method should be used? The optimized method is never appropriate when testing the better ear even if the unmasked AC thresholds differ by more than 20 dB. In this situation, the unmasked AC threshold of the TE would be better than the unmasked AC threshold of the NTE. A masking level set 10 dB below the unmasked AC threshold of the test (better) ear would be below the threshold of the nontest (poorer) ear and

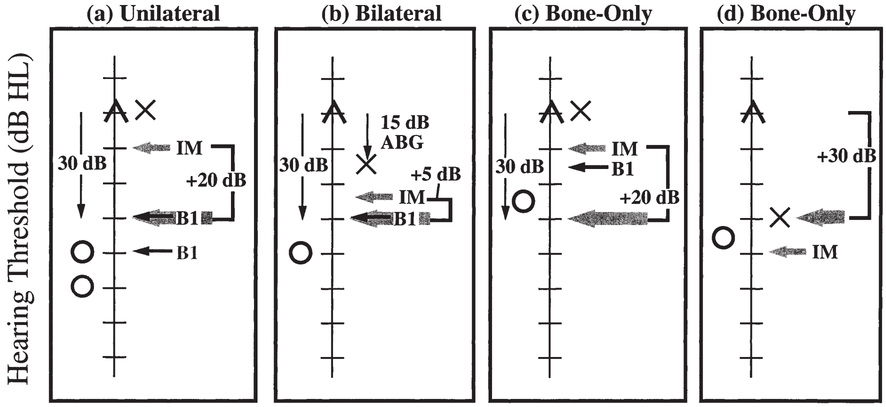

Figure 19. Adjusting initial masking levels for the occlusion effect. See text for explanation. See Figure 2 for an explanation of the audiometric symbols. ABG: air-bone gap. B1: initial masking level for bone-conduction testing using the optimized method. IM: initial masking level for the plateau method.

would not be audible. Overmasking is always a potential problem when testing the better ear. The safest approach is to use the plateau method with 5 dB masker steps.

Occlusion Effect

When using the plateau method and testing BC thresholds in the lower frequencies, it is necessary to increase the masking level to compensate for the occlusion effect. A variety of values have been proposed for supra-aural phones. Yacullo (1996, 63) recommends correction factors of 30 dB for 250 Hz, 20 dB for 500 Hz, 10 dB for 1000 Hz, and no correction for higher frequencies. These values are in addition to the usual 10 dB that is added to the AC threshold of the NTE. Roeser and Clark (2000) recommend 20 dB, 15 dB, and 5 dB. Goldstein and Newman (1994) recommend 15 dB, 15 dB, and 10 dB. The values for insert phones, when properly inserted, are significantly smaller than for supra-aural phones. For example, Yacullo (1996, 128) recommends 10 dB at 250 Hz and no correction at any other frequency.

Consider the unilateral pattern in Figure 19a. This is a worst case in that the apparent ABG equals the MIA (40 dB), the smallest possible for this pattern. We are using the plateau method and testing BC in the low frequencies. A correction factor of 20 dB is added to the initial masking level (IM) resulting in a masking level 30 dB greater than the unmasked BC threshold. If we were to use the optimized method, the initial masking level (B1) would be 10 dB below the AC threshold of the NTE, which would also be 30 greater than the unmasked BC threshold. Thus, the optimized method automatically adjusts for a correction factor up to at least 20 dB. If the apparent ABG is bigger than 40 dB (shaded circle), then the initial masking level (shaded B1) would compensate for an even larger correction factor.

The situation for a bilateral pattern is shown in Figure 19b. In this case, there is an apparent ABG of 15 dB in the NTE. A conductive hearing loss reduces the occlusion effect and essentially eliminates it when the ABG reaches 20 dB (Martin et al, 1974). Thus, the correction factor is reduced by the ABG. If the loss in the NTE is conductive, then the 20 dB correction factor would be reduced by 15 dB. It would only be necessary to add 5 dB to the initial masking level (IM). This results in a masking level 30 dB above the unmasked BC threshold. If we used the optimized method, the initial masking level (B1) would be placed at the same level, automatically compensating for the correction factor.

What if the loss in the NTE is sensorineural? The unmasked BC threshold could not be due to crossover to the NTE and would represent the actual BC threshold of the TE. Even if a tone at the BC threshold of the TE (assume 10 dB HL) was increased 20 dB by the occlusion effect, it would arrive at the NTE (at 30 dB HL), only 5 dB greater than the actual BC threshold of the NTE (25 dB HL). Increasing the initial masking level 5 dB (from 35 dB HL to 40 dB HL) would be sufficient to keep the masker 10 dB greater than the signal in the NTE. This places the masker at the same level as the initial masking level (B1) for the optimized method. Thus, it does not matter if the apparent ABG is actually conductive or sensorineural; the optimized method would automatically compensate for a correction factor up to 20 dB.

The symmetrical pattern is not shown in Figure 19. By definition, the symmetrical pattern requires an apparent ABG of at least 20 dB. This eliminates the need to adjust for any correction factor up to 20 dB. When using the plateau method with the symmetrical pattern, no modification to the initial masking level is required.

There is a potential problem with the bone-only pattern. The optimized method would be used with the threshold configuration in Figure 19c. The initial masking level (B1) would be significantly below the required masking level when using a 20 dB correction factor. Note, however, that the required masking level is 30 dB greater than the unmasked BC threshold, as was the case with the unilateral and bilateral patterns (Figures 19a, 19b). One strategy would be to always place the initial masking level at a level 30 dB greater than the unmasked BC threshold. This level would never cause overmasking because the minimum interaural attenuation is 40 dB for supra-aural headphones. Sometimes, the required initial masking level (IM) may be greater than 30 dB above the unmasked BC threshold. This can occur if the unmasked AC thresholds are close and the plateau method is being used (Figure 19d). In this situation, the greater masking level specified by the plateau method should be used.

MASKING PROTOCOL

Based on the evaluations of the optimized and plateau methods, a protocol can be constructed that is suitable for all masking situations. The optimized method should be used when the unmasked thresholds meet the requirements for a unilateral or a bilateral pattern. The key requirement is that the unmasked AC thresholds differ by at least 25 dB. For audiometric configurations corresponding to these two patterns, the optimized method correctly placed the last masking level in the plateau (or AMR) and yielded the actual threshold. The tradition plateau method, as defined for this paper, used 10 dB masker steps and required two increases in masking level (20 dB range) to define a plateau. With this definition, the plateau method could produce overmasking for certain audiometric configurations. The optimized method never required more masking levels than the plateau method and frequently required significantly fewer levels. In general, this advantage is greater for the unilateral pattern than the bilateral pattern.

The optimized method is never appropriate for the symmetrical pattern because unmasked AC thresholds, by definition, differ by less than 25 dB. With this pattern, the plateau or AMR can be small. The plateau method should be used with a 5 dB masker step to help identify a small plateau. An alternative strategy is to test first using 10 dB masker steps and retest with 5 dB steps if no plateau or AMR can be identified. There is still the possibility that masking will not be successful, even with 5 dB steps, in the case of the classic masking dilemma.

The optimized method can be used with the bone-only pattern when unmasked AC thresholds differ by more than 20 dB. When the difference is 20 dB or less, the plateau method should be used. Either use 5 dB masker steps or test first with 10 dB steps and retest with 5 dB steps if a plateau or an AMR cannot be identified.

If we use correction factors up to 20 dB for the occlusion effect, as specified by Roeser and Clark or Goldstein and Newman, then little modification to procedure is needed. For properly inserted insert phones, the correction factor is only 10 dB at 250 Hz, and, again, little modification is needed. For correction factors up to 20 dB, the optimized method automatically compensates for the unilateral and bilateral patterns. There is no need to make any adjustment when using the plateau method with the symmetrical pattern. The only exception would be the bone-only pattern. The initial masking level specified by the protocol may not always be adequate. A simple solution is to use the initial masking level specified by the protocol, or 30 dB greater than the unmasked BC threshold, whichever is larger. There is another advantage to setting the initial masking level no less than 30 dB greater than the unmasked BC threshold, even in the higher frequencies where the occlusion effect is not an issue. The higher masking level will help reduce testing time.

If a correction factor of 30 dB is being used for 250 Hz, as recommended by Yacullo, there is a solution. When testing 250 Hz, always set the initial masking level at least 40 dB greater than the unmasked BC threshold, although this may increase the possibility of overmasking. If the masking method being used specifies a larger value, use that.

Recommended Protocol

The following protocol can be used in all masking situations with supra-aural or insert phones.

When testing the poorer ear:

- If the unmasked AC thresholds differ by more than 20 dB, then use the optimized masking method.
- If the difference in unmasked AC thresholds is 20 dB or less, then there are two options:
  1. Use the plateau method with 5 dB masker steps
     or
  2. Initially use the plateau method with 10 dB steps. If no plateau or AMR can be identified, then retest using 5 dB steps.

When testing bone-conduction thresholds:

- Always set the initial masking level at least 30 dB greater than the unmasked BC threshold. If the masking method being used specifies a greater value, use that. This strategy automatically compensates for occlusion effect correction factors up to 20 dB.

When testing the better ear (this is seldom necessary for AC thresholds):

- Use the plateau method with 5 dB masker steps.

Note:

- Thresholds can be reestablished using the traditional up-down search or the single-tone procedure. The single-tone procedure will reduce testing time.
- Try to avoid high masking levels. Occasionally, the optimized method may specify a large increase in masking level, and that increase may produce a masker greater than 80 dB HL. When this occurs, consider using smaller increases in masking level to identify plateau.

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