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Masking Redux I: An Optimized Masking Method

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Abstract

This is the first 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 this paper, a masking method is developed 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, it can be significantly faster than the plateau method. There are some masking situations in which this optimized method cannot be used. This limitation will be evaluated in the second paper and an alternate masking strategy provided for use when the optimized method is not appropriate.

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; AC = air conduction; ATN = air-conduction threshold in the nontest ear; ATT = air-conduction threshold in the test 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; MEM = minimum effective masking; MIA = assumed minimum interaural attenuation; NTE = nontest ear; TE = test ear; XUM = maximum usable masking

Sumario

Este es el primero 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 este trabajo, se desarrolla un método de enmascaramiento que reemplaza el tradicional método del plateau, en la mayoría de las situaciones que requieren enmascaramiento. El nuevo método está optimizado para requerir menos niveles de enmascaramiento que el método del plateau. Como resultado, puede ser significativamente más rápido. Existen algunas situaciones donde este método optimizado no puede ser usado. Esta limitación será evaluada en el segundo trabajo, donde se aportará una estrategia alternativa de enmascaramiento para usar cuando el método optimizado no sea apropiado.

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

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; ATN = umbral de

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conducción aérea en el oído no evaluado; ATT = umbral de conducción aérea en el oído 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; MEM = enmascaramiento efectivo mínimo; MIA = supuesta atenuación interaural mínima; NTE = oído no evaluado; TE = oído evaluado; XUM = enmascaramiento máximo utilizable

The topic of masking hardly generates the same excitement among audiologists as hair cell regeneration, digital hearing aids, or the Au.D. Students rank masking with impedance and the decibel as the three most tedious, confusing subjects in their graduate education. What audiological topic could be more boring than masking? However, audiologists still spend much of their time generating audiograms, and masking is sometimes required to obtain accurate measures of threshold. Survey data from Martin et al (1994) suggest that all is not well in the world of masking. In fact, they state, "despite the large body of research regarding clinical masking, many audiologists use improper determinations for the need to mask and/or fail to mask using a logical method" (Martin et al, 1994, p. 26). A more recent survey (Martin et al, 1998) also demonstrates that many audiologists continue to use inappropriate masking procedures.

The most common masking procedure is the plateau method; 58% of survey respondents report using some variant of this technique (Martin et al, 1994). Disturbingly, more than 40% did not use the plateau method. Seven percent used an "arbitrary" level for masking, and 26% categorized their procedure as "other." The plateau method is well established in the research literature and works quite well when properly administered. A review of audiology textbooks indicates that the plateau method is the procedure consistently described.

Why is it that so many audiologists do not use the plateau method? The plateau method has many advantages, but it has one significant disadvantage. It can be extremely time consuming. Our experiences indicate that students who are taught the plateau method frequently abandon this technique when they leave the unique environment of the academic clinic. In many clinical settings, time for testing is significantly limited. The plateau method appears impractical in these situations, and students, or graduates, adopt "shortcut" masking procedures, typically acquired from supervisors or coworkers. The problem is that these shortcut procedures may not be based on theoretical principles or validated in any way. These procedures may work in certain situations, suggesting their validity, but fail in other situations with the audiologist unaware of these failures.

The objective of this paper is to describe a masking method that (1) yields valid measures of threshold, (2) is as simple to perform as the plateau method, and (3) is more time efficient than the plateau method. This is the first step in developing a recommended masking protocol that can be used in all masking situations. The masking method developed in this paper can replace the plateau method in most, but not necessarily all, masking situations. The limitations of this new method will be evaluated in the second paper in this series (Turner, 2003).

This paper is not an introductory tutorial on masking; it is assumed that the reader has a basic understanding. It will be necessary, however, to review some principles, as they are needed to describe the derivation of the new method.

THE PLATEAU METHOD

The plateau method was first described by Hood (1960) over four decades ago. Interestingly, Hood presented this technique for bone-conduction testing and never used the word "plateau" in his article. Hood's procedure was adapted to air-conduction testing and became known as the "plateau method." The plateau method is typically described using a masking diagram as shown in Figure 1a. A tone is presented to the test ear (TE) by air conduction (AC) or bone conduction (BC). A masking noise is presented to the nontest ear (NTE) by air conduction. The noise is calibrated in terms of effective masking. For this paper, the definition of

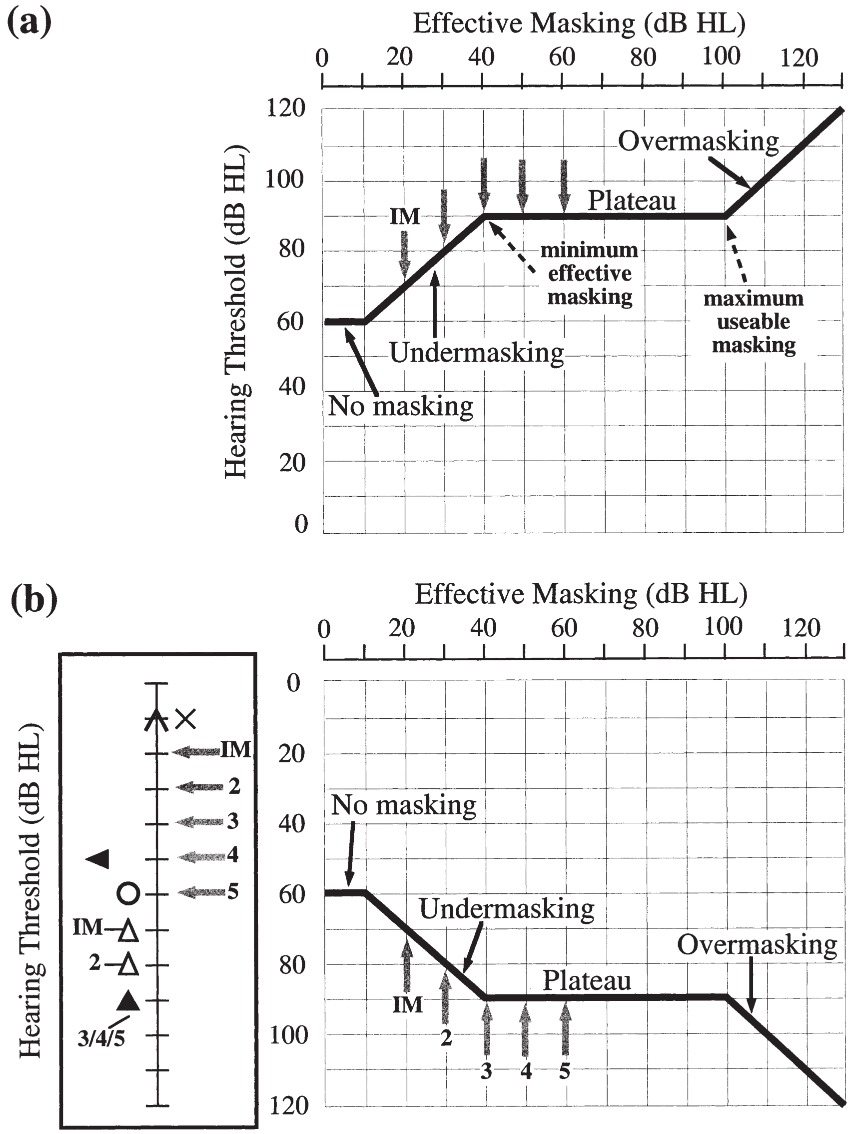

Figure 1. Traditional masking diagram. (a) Modified masking diagram and frequency diagram. (b) The modified masking diagram inverts the ordinate (Hearing Threshold) so as to be consistent with the audiogram. Both masking diagrams show thresholds as a function of effective masking level. The shaded arrows represent masking levels for the plateau method. The frequency diagram represents one frequency, the test frequency, on the audiogram. See Figure 2 for a key to the audiometric symbols. IM: initial masking level.

"effective masking" is consistent with ANSI S3.6, 1989. For example, a 60 dB HL tone would just be audible with an effective masker of 60 dB HL presented to the same ear. This differs slightly from another definition occasionally used in which a 60 dB HL effective masker would just mask a 60 dB HL tone (Martin, 1986).

AIR ———	Unmasked	Masked	Actual
Right	O	△	▲
Left	×	□	■

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

Figure 2. Key to the audiometric symbols used in the figures.

The traditional masking diagram depicts the threshold responses of the individual as the masking level is increased (Figure 1a). (An explanation of the audiometric symbols used in this and other figures is given in Figure 2.) In this example, the actual AC threshold of the TE is 90 dB HL, and the actual BC threshold is 50 dB HL. The AC response at 60 dB HL occurs because of crossover to the NTE. The actual AC and BC thresholds of the NTE are 10 dB HL.

The masking curve can have several distinct regions defined by inflection points in the curve. Masking diagrams are easily constructed once the locations of the inflection points are determined. The first inflection point occurs when the masking level equals the AC threshold in the NTE. If the masker is presented at a level below 10 dB HL, then the masker would not mask the NTE. Thus, this would be a region of "no masking." Of course, this is not common clinical practice. When the masking level exceeds the AC threshold of the NTE, there would be masking of the NTE. If the unmasked threshold was due to crossover to the NTE, then the threshold would increase when the NTE is masked. This would be the region called "undermasking." In this region, the threshold of the NTE is being elevated by the masker, but the tone has not reached the threshold of the TE. Thus, the tone is audible in the NTE but is not audible in the TE.

The next region is the "plateau." The plateau is the masking range between the two inflection points corresponding to the minimum effective masking (MEM) and the maximum usable masking (XUM). Minimum effective masking is the minimum masking level that makes the test tone at the threshold of the TE inaudible to the NTE, and it occurs at the first inflection point. Maximum useable masking is the maximum masking level before the masker crosses over and elevates the threshold in the TE. In the plateau, the tone is audible to the TE. The tone is not audible in the NTE because of the masker, and the masker is not sufficiently intense to cross over and elevate thresholds in the TE. The threshold measured in the plateau is the actual threshold of the TE. The masking levels at which the minimum effective masking and maximum usable masking occur can be calculated using equations first provided by Liden et al (1959). These equations are shown below with some modification. For AC testing

$$MEM(A) = ATT + ABGN - IA \quad (1)$$
$$XUM(A) = BTT + IA \quad (2)$$

where ATT is the actual AC threshold of the TE, ABGN is the actual air-bone gap (ABG) in the NTE, BTT is the actual BC threshold in the TE, and IA equals the actual interaural attenuation for air conduction. For BC testing,

$$MEM(B) = BTT + ABGN \quad (3)$$
$$XUM(B) = BTT + IA \quad (4)$$

The original equations of Liden et al ignored the occlusion effect that will be considered in more detail in the second paper.

As the masking level is increased, the threshold tone remains audible in the TE until the masker crosses over to the TE at a sufficient level to mask the response of the TE. As the masking level continues to increase, the masked threshold of the TE continues to increase. In this region, called "overmasking," the tone is not audible in the NTE but is audible in the TE at an elevated level above the actual threshold.

The basic procedure as described by Hood:

1. Establish unmasked thresholds.
2. If required, apply masking to the NTE and reestablish threshold.
3. Increase the masking level in 10 dB steps until the measured threshold "remains constant with further additional incremental steps of 10 dB" (Hood, 1960, p. 1227).

Several variations on the plateau method have been suggested. It is worthwhile to review some of these modifications. The first issue is when to mask. For AC thresholds, Hood recommended masking when the difference in AC thresholds exceeds 50 dB. The accepted current recommendation is to mask when the AC threshold in the TE exceeds the BC threshold of the NTE by a specified amount, the assumed minimum interaural attenuation (MIA). For supra-aural headphones, this value is typically 40 dB, independent of frequency. This value is larger for insert phones. (Yacullo, 1996, 21, 128). In this paper, we will assume that supra-aural headphones are being used. This is the more difficult masking situation than with insert phones. Any procedure that will work with supra-aural headphones will work with insert phones.

For BC testing, the interaural attenuation can be as small as 0 dB. Thus, some, including Hood, recommend always masking BC thresholds. There is no problem with this strategy except that it takes more time. Another recommendation, the one used in this paper, is to mask when the AC threshold in the TE exceeds the BC threshold in the NTE by more than 10 dB (Yacullo, 1996, 26). If available, the masked BC threshold in the NTE would be used; otherwise, use the unmasked threshold. It is not that small ABGs are always unimportant. The rationale is that the BC threshold can shift up to 10 dB due to test variability and central masking. Thus, the closure of an apparent 10 dB ABG would not necessarily prove that there is no ABG.

Hood did not specify the initial masking level (IM). Martin (1974) has recommended

$$IM = ATN + 10\ dB \quad (5)$$

where ATN is the AC threshold of the NTE. The 10 dB is a safety factor to account for test and subject variability and to insure that the masker actually masks the NTE. An additional factor for the occlusion effect may be required for BC testing.

One variation that can reduce the time required to perform the plateau method is to not reestablish threshold using the traditional up-down search for threshold (Yacullo, 1996, 73). Instead, the tone is presented once. If there is a response, that is taken as 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.

Hood recommended increasing the masking level in 10 dB steps, but some (Roeser and Clark, 2000) recommend 5 dB steps. The use of 5 dB steps would essentially double the number of masking levels and increase testing time. Using 5 dB steps would be useful if the plateau were narrow and difficult to define.

If the unmasked threshold does not change with the initial masking, some recommend accepting the unmasked threshold as the actual threshold. This would reduce testing time. It is generally recommended, however, that the masking level be increased at least once to ensure that the NTE is adequately masked (Studebaker, 1967). Hood does not specify the number of increases of masking level needed to define the plateau region. It is generally recommended that the masking level be increased over a range of at least 15 to 20 dB with little change in tone threshold (Yacullo, 1996, 73).

The time required to perform the plateau method is an issue in this paper. Obviously, that time is a function of the specific plateau procedure used. Reestablishing threshold using the traditional up-down search and using 5 dB masker steps would produce the slowest procedure. Using a single tone presentation at each tone level to reestablish threshold, as discussed above, and using 10 dB masker steps would produce the quickest procedure. The masking method described in this paper will be compared to the plateau method. For this purpose, the plateau method will be defined as the following:

1. Set the initial masking level (IM) 10 dB above the AC threshold of the NTE and reestablish threshold.
2. The masking level is increased 10 dB and threshold reestablished.
3. 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.

The plateau method is illustrated by the shaded arrows in the masking diagram (Figure 1a). Each arrow represents a masker presentation, and the arrows conform to the definition above.

MASKING AND FREQUENCY DIAGRAMS

Masking diagrams will be use extensively in this and the subsequent paper, but with a modification as shown in Figure 1b. The ordinate (Hearing Threshold) is reversed from that in Figure 1a. This was done so as to be consistent with the audiogram; that is, threshold increases in the downward direction. The plateau method is also represented with shaded arrows in the masking diagram in Figure 1b. In all masking diagrams, the right ear will be the TE and the left the NTE.

To the left of the masking diagram is a frequency diagram, corresponding to one frequency on an audiogram. The frequency diagram will be used to represent a variety of information. The various masking levels used are represented by the arrows to the right of the axis. These correspond to the arrows on the masking diagram. Unmasked AC thresholds are shown using conventional symbols (right—60 dB HL; left—10 dB HL). The unspecified symbol for unmasked bone (10 dB HL) is used because an unmasked

BC threshold cannot, in general, be associated with a particular ear. Masked thresholds (70, 80 dB HL) are shown using conventional symbols and actual thresholds (AC—90dB HL; BC—50 dB HL) are represented by filled symbols. If the actual threshold equals the unmasked threshold, then only the unmasked threshold is shown so as to reduce clutter. It is also possible to indicate what masking level(s) produces a particular masked threshold. In Figure 1b, IM resulted in a masked AC threshold in the right ear of 70 dB HL. Masking levels 3, 4, and 5 elevate threshold to the actual threshold, because they are in the plateau region.

The masking and frequency diagrams are generated based on theoretical considerations. Two factors that could influence actual threshold measurements are ignored. These are test variability and central masking. The measurement of threshold can vary, typically about ± 5 dB. In addition, central masking can increase threshold by an average of 5 dB. The implications of these factors to masking procedures are discussed later in this paper. They would, however, add unnecessary complexity to the masking and frequency diagrams and have, therefore, been ignored.

OPTIMIZED MASKING METHOD

The new masking method is similar to the plateau method and should be at least as easy to perform. It is called the optimized method because it has been optimized in several ways to reduce testing time. In many masking situations, this optimized method can significantly reduce the number of masking levels required to reach the plateau and determine threshold. Fewer masking levels result in less testing time. This method is described below and is applicable for AC and BC testing.

1. Measure an unmasked AC threshold for each ear and an unmasked BC threshold.

The unmasked BC threshold could correspond to the actual BC threshold of the TE, the NTE, or both.

2. At each frequency, determine if masking is required using conventional criteria.

Because there is a single unmasked BC threshold, it is assumed, until shown otherwise, that this represents the actual BC thresholds of both ears. To determine the need for masking AC or BC thresholds, the unmasked AC threshold is compared to the unspecified unmasked BC threshold. When this difference equals or exceeds the MIA, then masking is required for the AC threshold. When this difference exceeds 10 dB, then masking is required for the BC threshold.

3. Set the initial masking level (A1 or B1) equal to the AC threshold of the TE minus 10 dB and reestablish threshold.

A1 is the initial masking level for air-conduction testing. B1 is the initial masking level for bone-conduction testing. These two initial levels will always be equal. Subsequent masking levels may differ for air- and bone-conduction testing. In general, the level of B1 is sufficient to compensate for the occlusion effect when testing low frequencies, and no additional correction is needed. This is discussed in detail in the second paper.

With this strategy, the initial masker is set relative the threshold of the TE. This is a major difference from the plateau method where the initial masking level (IM) typically equals the AC threshold of the NTE plus 10 dB. One way the new method is optimized is that it attempts to use the maximum possible masking without overmasking. To accomplish this, the masking level must be referenced to the threshold of the TE, not the NTE. The plateau and other masking methods reference the initial masker to the threshold of the NTE.

The optimized method is based on the principle that setting a masking level 10 dB below the AC threshold of the TE will never result in overmasking. This is illustrated in Figure 3a. In this example, we have used an MIA equal to 40 dB. The unmasked AC threshold of the TE (right) is at 70 dB HL, 60 dB above the unmasked BC threshold. Since the MIA is 40 dB, masking is needed. In this method, the initial masking for air conduction (A1) and bone conduction (B1) is set at 60 dB HL, which is 10 dB below the AC threshold of the TE. Thus, the masking level is 50 dB above the unmasked BC threshold, and this exceeds the MIA. Can this level of masker produce overmasking? Even though we used

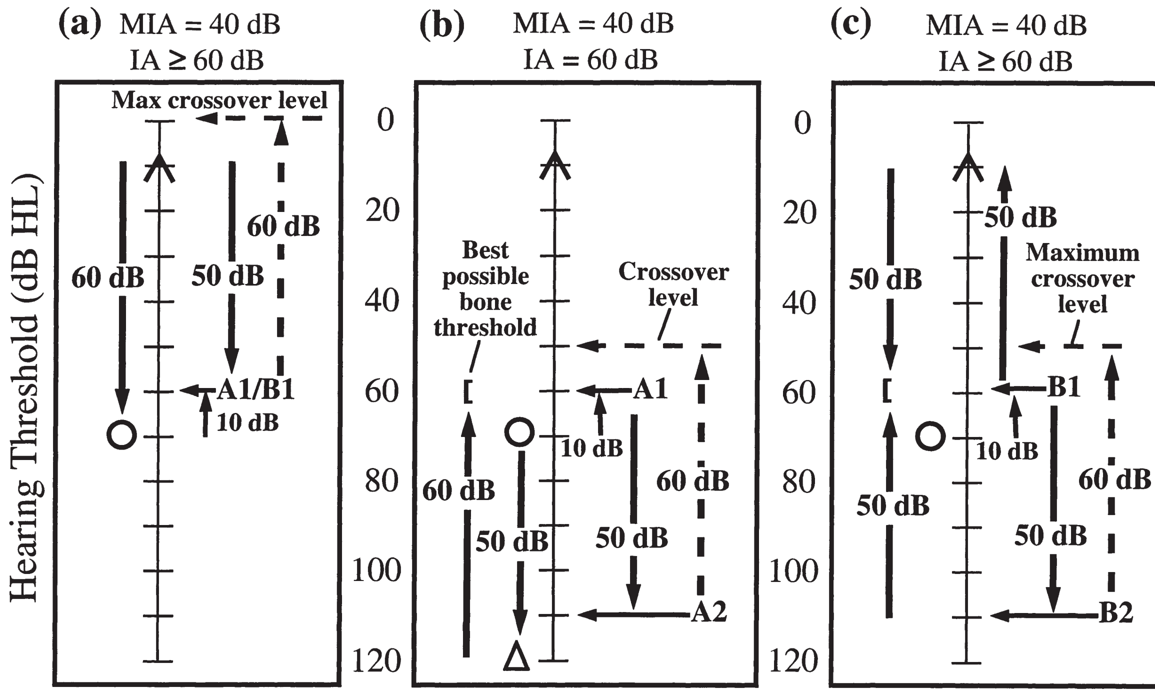

Figure 3. Justification of strategies used in optimized masking protocol. See text for details. See Figure 2 for a key to the audiometric symbols. A1: initial masking level for air-conduction testing using the optimized method; A2: additional masking level for air-conduction testing using the optimized method. B1: initial masking level for bone-conduction testing using the optimized method; B2: additional masking level for air-conduction testing using the optimized method.

an MIA of 40 dB to determine the need for masking, the IA in this example must be at least 60 dB. An explanation of why this is true will be provided later. Overmasking would occur if the masker at 60 dB HL could cross over to the TE at a level sufficient to mask the TE, that is, at a level above the actual BC threshold of the TE. The worst case for overmasking would occur if the actual BC threshold of the TE equaled the unmasked BC threshold. Even in this situation, however, overmasking would not occur. The masker at 60 dB HL would be reduced by the IA that is at least 60 dB. Thus, the masker would reach the TE at a maximum level of 0 dB HL, less than the best possible BC threshold of the TE (10 dB HL). This argument applies equally well to BC testing. Since overmasking occurs by the same mechanism in AC and BC testing, a masking level that does not overmask for AC testing will not overmask for BC testing.

In the example in Figure 3a, there is an apparent ABG of 60 dB. This tells us that the IA must be at least 60 dB. To demonstrate why this is true, we must consider two possibilities: (1) the actual BC threshold of the NTE equals the unmasked BC threshold; (2) the actual BC threshold of the TE equals the unmasked BC threshold. Consider the first possibility that the unmasked BC threshold corresponds to the NTE. In this situation, there is a 60 dB difference between the unmasked AC threshold of the TE and the BC threshold of the NTE; thus the IA must be at least 60 dB. If the IA were less than 60 dB, the unmasked AC threshold of the TE would have occurred at a better threshold, for example, 50 dB HL.

Next, consider the second possibility that the unmasked BC threshold equals the actual BC threshold of the TE indicating an actual ABG of 60 dB. Assume that the actual BC threshold of the NTE is poorer, for example, 30 dB HL. Could the unmasked AC threshold in the TE (70 dB HL) be due to crossover to the BC threshold of the NTE (30 dB HL) indicating an IA of 40 dB? If the IA were 40 dB, then an AC signal to the TE at 70 dB HL would stimulate the cochlea of the NTE by bone conduction at a level of 30 dB HL. This is at the BC threshold of the NTE and would just be audible. What is often not recognized is that this signal would also reach the cochlea of the TE at about 30 dB HL because the interaural attenuation for bone conduction is as little as 0 dB and the NTE is being

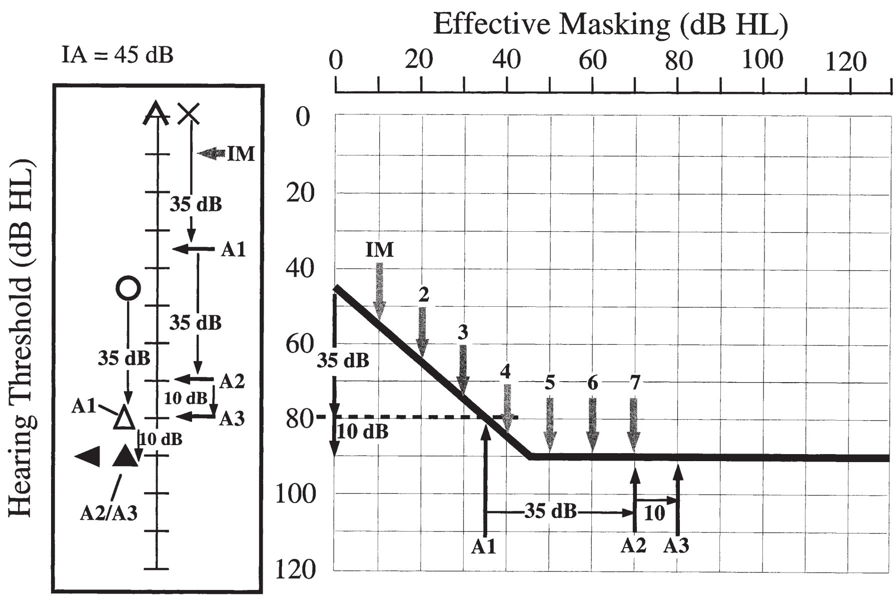

Figure 4. Comparison of plateau and optimized masking methods for determining an AC threshold. The shaded arrows represent masking levels for the plateau method. The solid arrows represent masking levels for the optimized method. The plateau method requires seven masking levels to determine threshold. The optimized method only requires three masking levels. See Figure 2 for a key to 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. IM: initial masking level for the plateau method.

stimulated by bone conduction. Stated differently, a signal that can sufficiently vibrate the skull so as to stimulate the cochlea of the NTE at 30 dB HL will also stimulate the cochlea of the TE at about 30 dB HL. Since 10 dB HL is the BC threshold of the TE, this signal would be 20 dB above that BC threshold. Obviously, a lower-level signal would be audible to the TE. If the IA were 40 dB, then an AC signal to the TE at 50 dB HL would stimulate the cochlea of the TE by bone conduction at a level of 10 dB HL and would be audible. Thus, the unmasked AC threshold of the TE would occur at 50 dB HL, not 70 dB HL, and the ABG would be 40 dB. Since the unmasked AC threshold of the TE is 70 dB with an ABG of 60 dB, the IA must be at least 60 dB. This illustrates a fundamental principle upon which this masking strategy is based. An ABG cannot be greater than the IA, although it can, of course, be less. The unmasked AC threshold in the TE (70 dB) cannot be due to crossover to the BC threshold of the NTE (30 dB) because that would mean an ABG in the TE significantly greater than the IA, which is not possible.

The apparent ABG in the TE in Figure 3a is 60 dB. For both possibilities, the IA had to be at least 60 dB supporting the statement that the IA cannot be less than the apparent ABG. In general, the IA could be greater than 60 dB because the unmasked AC threshold in the TE could be the actual threshold and not due to crossover to the NTE.

There is, of course, some test variability in the measurement of threshold and the effectiveness of masking. That is why the masking level is set 10 dB below the AC threshold of the TE. This provides a safety margin to account for test and subject variability. Theoretically, the masking level could be set equal to the AC threshold of the TE and not result in overmasking. Referencing the masking level to the threshold of the NTE can result in using less than the maximum permissible masking, as shown in Figure 4. Also, setting the masking level some fixed amount, for example, 30 dB, above the threshold of the NTE could result in overmasking as in the case of bilateral conductive loss.

This step calls for reestablishing the threshold. As discussed above for the plateau method, threshold can be reestablished using the traditional up-down procedure or the single-tone procedure that can significantly decrease testing time.

4. Determine the dB shift in threshold due to the masker.

This is the difference between the unmasked threshold and the masked threshold due to the initial masking level, A1 or B1.

5. Increase the masking level an amount equal to the threshold shift and reestablish threshold.

This new masking method is optimized in a second way. It increases the masking level the maximum amount without overmasking. Increasing the masking level an amount equal to the threshold shift will not result in overmasking, as illustrated in Figure 3b. In this example, the threshold shifted 50 dB to 120 dB HL in response to the masker; thus, the masking level is increased 50 dB to 110 dB HL. Note that the masker is still 10 dB less than the masked AC threshold. When testing AC thresholds, this method keeps the masking level 10 dB below the masked AC threshold in the TE. Because the threshold in the TE shifted, we know that the unmasked threshold was due to crossover to the NTE and the IA equals 60 dB. Since an ABG cannot exceed the IA, the largest possible ABG in this example is 60 dB. Thus, the best possible BC threshold in the TE is 60 dB HL. The masker, which is at 110 dB HL, would reach the TE at a level of 50 dB HL, 10 dB below the BC threshold. Overmasking would not occur.

A similar argument can be made for BC testing (Figure 3c). The initial masking level (B1) is 10 dB below the AC threshold of the TE and, thus, 50 dB above the unmasked BC threshold. In this example, the BC threshold in the TE elevates 50 dB in response to the masker. The masking level is increased 50 dB to 110 dB HL. For BC testing, the masking level is always maintained the same dB above the BC threshold, 50 dB in this example. The IA is at least 60 dB; thus, the maximum crossover level of the masker to the TE would be 50 dB HL, below the level of the masked BC threshold. Overmasking would not occur.

Even if the unmasked threshold is the actual threshold and the shift is due to test variability and/or central masking, increasing the masking level an equal amount is appropriate. If the threshold shifts 5 dB due to test variability, increasing the masking level 5 dB should not overmask. The subsequent threshold should remain constant or improve, indicating actual threshold. If the threshold shifts 5 dB due to central masking, there is no way to determine this. Increasing the masking 5 dB will not overmask. Again, the subsequent threshold will be the appropriate threshold to record as the actual threshold. There is disagreement as to whether there should be a correction for central masking. That issue is not addressed in this paper.

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 5–6.

If the threshold improves or does not shift with the initial masking level, then the unmasked threshold is the actual threshold. As noted above, it has been recommended that at least one additional masking level be used to identify the plateau. With this method, the initial masking level is usually much greater than the AC threshold of the NTE, sufficient to shift threshold if the unmasked threshold is due to crossover to the NTE. However, it is generally acceptable to use a second level 5 dB to 10 dB greater to confirm that the unmasked threshold is the actual threshold. The only limitation is the case of significant bilateral conductive loss where the plateau can be small. This situation is discussed in the next paper.

If the threshold shifts with the initial masker level, then additional levels are used until the plateau is identified. If a single stimulus presentation is used at each masker level instead of reestablishing threshold, then threshold must be accurately measured once the plateau has been identified.

OPTIMIZED VERSUS PLATEAU METHOD

Masking diagrams can be used to illustrate the optimized method and to compare it to the plateau method. The application to AC testing is shown in Figure 4. From the frequency diagram, it is evident that there is a severe, unilateral, sensorineural loss in the right ear. The right unmasked AC threshold is 45 dB greater than the unmasked BC threshold. We will use an MIA of 40 dB. Thus, we need to use masking for the right AC threshold. With the plateau method, the IM would be 10 dB HL. The masking level would be increased in

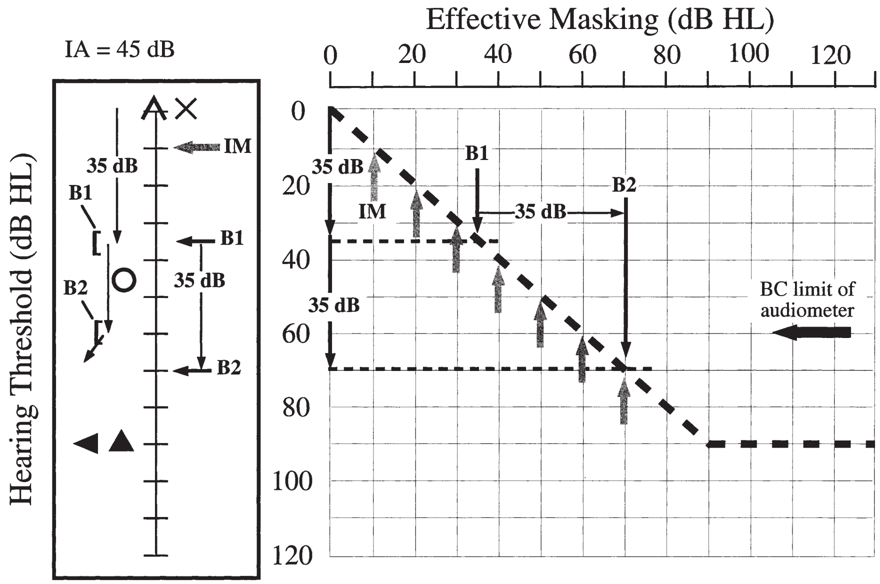

Figure 5. Comparison of plateau and optimized masking methods for determining a BC threshold. The shaded arrows represent masking levels for the plateau method. The solid arrows represent masker levels for the optimized method. The plateau method requires seven masking levels to determine threshold. The optimized method only requires three masking levels. See Figure 2 for a key to 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. IM: initial masking level for the plateau method.

10 dB steps until the plateau is defined. This would require the use of seven masking levels, as shown in Figure 4 by the broad, shaded arrows.

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 35 dB. This level (A2) produces a 10 dB shift in threshold. Because the threshold shift (10 dB) was much less than the increase in masking level (35 dB), we have strong evidence that A2 is in the plateau. The other possibility is that the masker passed over a small plateau and is overmasking. That, however, would only occur with significant bilateral conductive loss.

We could take the threshold obtained with A2 as the actual threshold. Consistent with the method, however, 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. Even if the threshold shifts (poorer) 5 dB due to test variability, we are still confident that we are in the plateau because the masking level has been increased 45 dB (A1 to A3), and the threshold has only shifted 15 dB. If desired, the masking level could be increased another 5 dB to confirm the plateau. This example demonstrates the advantage of the optimized method relative the plateau method. The optimized method requires three masking levels to obtain actual threshold, whereas the plateau method requires seven.

The optimized method can also be used for BC testing (Figure 5). This is the same threshold configuration as in Figure 4. The unmasked thresholds indicate the possibility of an ABG in the right ear greater than 10 dB. Thus, masking is required for the BC threshold in the right ear. As it was for AC testing, the initial masking (B1) is set at 35 dB HL. This produces a threshold shift of 35 dB; thus, the masking level is increased 35 dB to 70 dB HL. This masker (B2) shifts the BC threshold beyond the limit of the audiometer, which is assumed to be 60 dB HL for this example. Using the optimized method, it took two masking levels to establish BC threshold. Had the plateau method been used, it would have required seven levels to shift the threshold beyond the limits of the audiometer.

DISCUSSION

The objective is to recommend a masking protocol that is easy, fast, and valid. If successful, then this protocol may be practical in clinical environments where speed is essential. This protocol may be attractive to audiologists who have adopted shortcut masking procedures because the plateau method is perceived as being too slow. There is an additional advantage to reduced testing time. Fewer masking levels at multiple frequencies would reduce listener fatigue. This could be particularly useful with children and the elderly.

The first step is the development of an optimized masking method that can replace the plateau method in many masking situations. The procedure for the optimized masking method 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 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.

The optimized masking method is not as complex as it may appear. In procedure, it differs from the plateau method in only two significant ways. First, the initial masking level is set 10 dB below the AC threshold of the TE. With the plateau method, initial masker level is 10 dB above the AC threshold of the NTE. Second, the masking level is increased an amount equal to the masked threshold shift. With the plateau method, the masking level is increased a fixed amount, usually 5 or 10 dB. Both of these differences are easy to remember; the optimized method should be as easy to administer as the plateau method.

The optimized method is faster than the plateau method because fewer masking levels are required to reach plateau and determine threshold. The actual time advantage, however, depends on threshold configuration and can be greater or less than that shown in the examples above (Figures 4, 5). This issue will be examined in detail in the next paper.

As discussed above for the plateau method, threshold can be reestablished using the traditional up-down search or the single-tone procedure. There is no reason that the single-tone procedure cannot be employed with the optimized method provided threshold is reestablished with the more accurate up-down procedure once the plateau is identified. This strategy would increase the time efficiency of the optimized method.

The optimized method is based on accepted theoretical principles. One lesser known principle is that an air-bone gap cannot be greater than the actual interaural attenuation that is determined by the type of headphone. Thus, a consequence of this principle is that the headphone determines the maximum conductive loss, that is, ABG, that can be recorded on an audiogram. Historically, the maximum conductive loss was thought to be about 60 dB. This actually resulted from using supra-aural headphones that typically provided a maximum IA of about 60 dB. With the use of insert earphones, which can produce a greater IA, it is possible to see ABGs in the 70 dB to 80 dB range.

Is the optimized method appropriate and valid in all masking situations? In the next paper, the optimized method will be evaluated for a variety of threshold configurations. Masking diagrams will be used to determine the ability of the optimized method to place the masker within the plateau region and, thus, determine threshold. There are, in fact, some limitations on the use of the optimized method. The exact nature of these limitations will be described as well as an alternate masking strategy that can be used in those situations where the optimized method is not appropriate.

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