Masking theory in pure tone audiometry
– Systematic lectures – Part 2

Part 2 **Lecture 3: A basic principle of the plateau method**
Lecture 4: Implications of the AB gap ≤ IaA relationship
Lecture 5: Theoretical masking procedure

Lecture 3: Focal point

Typical AC and BC plateau widths of the left ear (Lt APW, Lt BPW) are as follows:

Lt APW = (IaA − GR*) + (IaA − GL*),

Lt BPW = (IaA − GR*) + IaB,

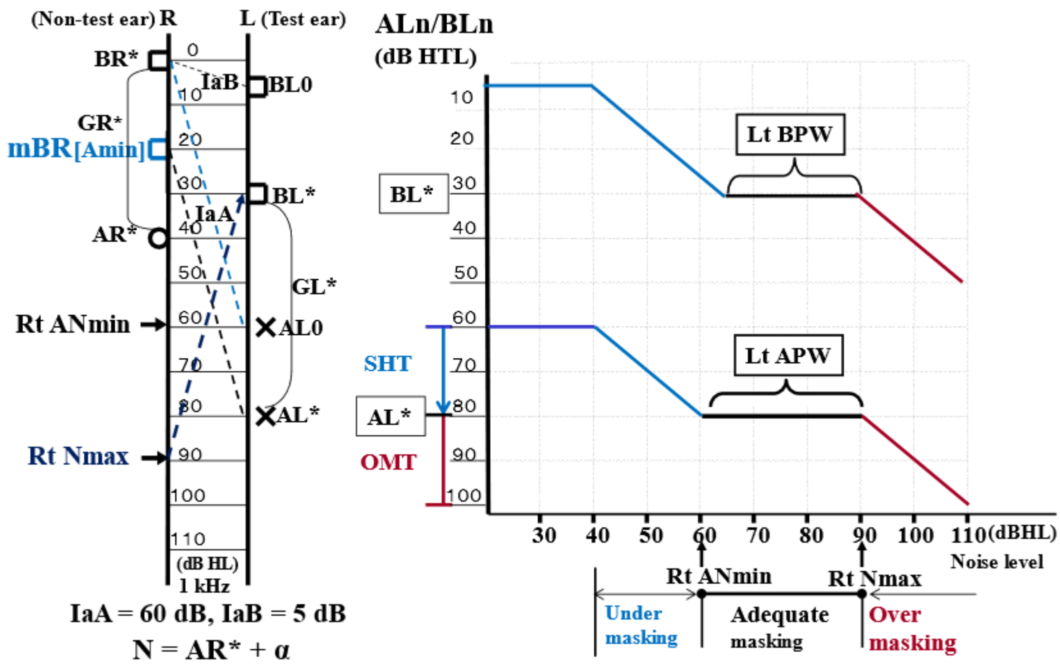
where IaA is the interaural attenuation for air-conduction (AC) signals,
IaB is the interaural attenuation for bone-conduction (BC) signals,
GR* is the true AB gap of the right ear (= AR* − BR*), and
GL* is the true AB gap of the left ear (= AL* − BL*).
AR*: Right ear's true AC threshold, BR*: Right ear's true BC threshold.
AL*: Left ear's true AC threshold, BL*: Left ear's true BC threshold.

General expressions of AC and BC plateau widths are as follows (cf. Lecture 7):

Lt APW = Rt δ + Lt SNC − ω,

Lt BPW = Rt δ + IaB.

where Rt δ = (IaA − GR0), Lt SNC = (BL* − BR*), ω = (AL* − AL0).
GR0: Right ear's apparent AB gap of the right ear (= AR0 − BR0).
AR0: Right ear's apparent AC threshold, BR0: Right ear's apparent BC threshold,
AL0: Left ear's apparent AC threshold, BL0: Light ear's apparent BC threshold.



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Lecture 4: Focal point

According to the relationship AB gap ≤ IaA, the maximum level of the true AC threshold possible in the right ear (max AR*) and the left ear (max AL*) are determined as follows:

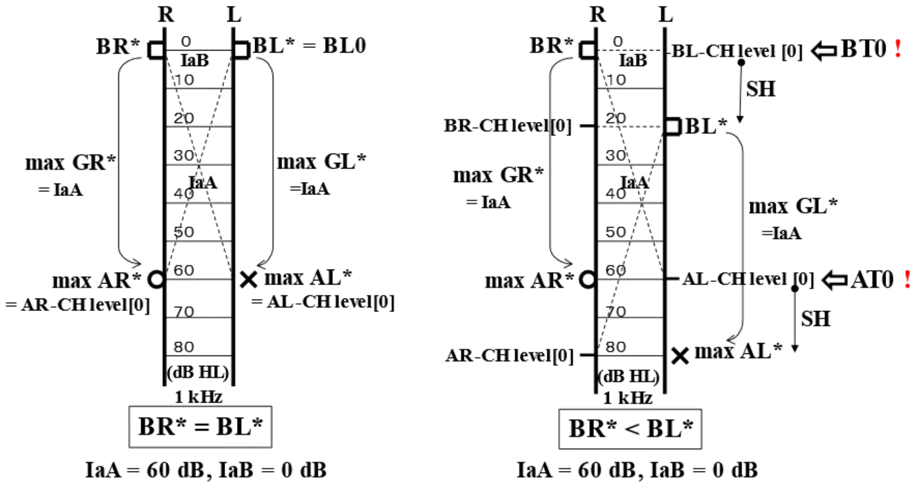
max AR* = BR* + IaA,

max AL* = BL* + IaA.

When bilateral true BC thresholds are at the same level (BR* = BL*) at some frequency, all the apparent AC and BC thresholds are not the shadow (SH) but always the true hearing thresholds.

The requirement for the apparent BC threshold to be the SH threshold is that bilateral true BC thresholds differ (BR* < BL*), i.e., a necessary and sufficient condition. The apparent BC threshold in the poorer ear by BC (BL0) is always the SH threshold.

The requirements for the apparent AC threshold to be the SH threshold are that bilateral true BC thresholds differ (BR* < BL*), i.e., a necessary condition, and that the true AC threshold in the poorer ear by BC (AL*) is higher than the CH level [0] for AC in the same ear, i.e., a sufficient condition. Then, the apparent AC threshold in the poorer ear by BC (AL0) is always the SH threshold.

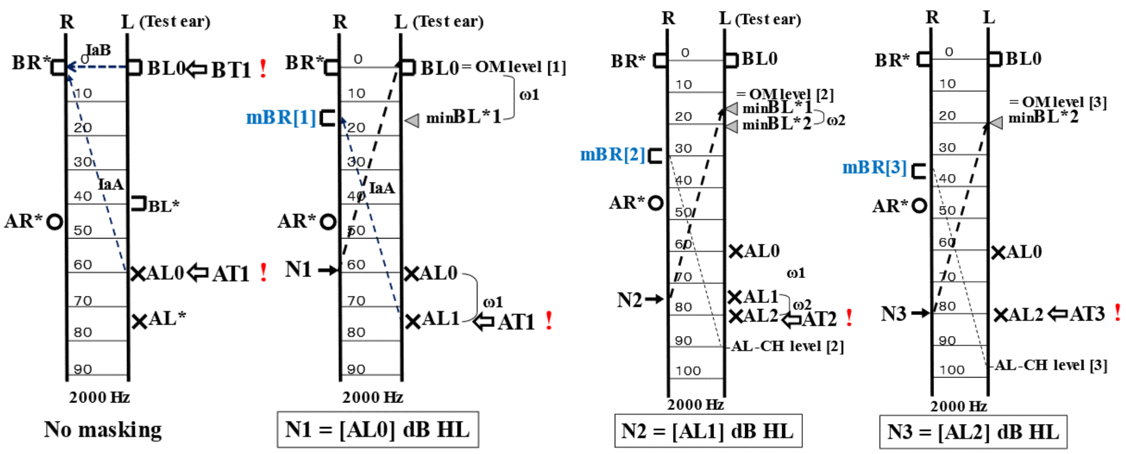


Lecture 5: Focal point

When bilateral apparent AC thresholds differ significantly (AR0 < AL0, Rt AA gap = AL0 − AR0 ≥ 15 dB) and Lt AOB gap = AL0 − BR0 ≥ 40 dB), the test ear is the left, poorer ear by AC and the non-test ear is the right, better ear by AC.

The n-th masking noise (Nn) of the level that is equal to the AC threshold level measured in the left (test) ear with Nn-1 (ALn-1) is presented to the right ear: Nn = [ALn-1], (n = 1, 2, 3, …).

The present masking procedure using the maximum level of masking noise that has no possibility of OM (MNnpo) is theoretically the most efficient option.



Lecture 3 The basic principle of the plateau method

The plateau method is the basic principle that forms the backbone of all masking methods. In this lecture, we present an in-depth description of shadow hearing, true hearing, and overmasking, which provide the foundation for typical plateau width formulations.

**** Further note ****

*) The main abbreviations are listed. AC: Air conduction, BC: Bone conduction,
SH: Shadow hearing, OM: Overmasking,
GR*: True air-bone (AB) gap in the right ear, GR0: Apparent AB gap in the right ear,
IaA: Interaural attenuation for AC signals, IaB: Interaural attenuation for BC signals,
AL-CH level [0]: CH level for AC in the left ear without masking.
AL-CH level [1]: CH level for AC in the left ear with N1.

3.1 Air-conduction audiometry

3.1-1 An audiometric configuration without masking

Let us consider the following audiometric configuration at 1000 Hz (**Fig. 3-1 [a]**):

	Non-test (right) ear	Test (left) ear	Interaural attenuation
Bone conduction (BC)	BR* = 0 dB HTL	BL* = 30 dB HTL	IaB = 0 dB
Air conduction (AC)	AR* = 40 dB HTL	AL* = 80 dB HTL	IaA = 60 dB
Air-Bone gap (AB gap)	GR* = 40 dB	GL* = 50 dB	

The configuration presented in **Fig. 3-1 (b)** is obtained without masking. Both the apparent AC and BC thresholds in the left ear (AL0, BL0) are shadow-hearing (SH) thresholds because the participant barely hears the AC test signal, which is at the same level as the AL-CH level [0] (i.e., AT0 = 60 dB HL) (**Fig. 3-1 [c]**, cf. **2.1-2**). The same holds true for BC (i.e., BT0 = 0 dB HL).

In this configuration, typical AC and BC plateaus are obtained. For simplicity, it is assumed that the non-test ear is the right, better ear by AC and the test ear is the left, poorer ear by AC.

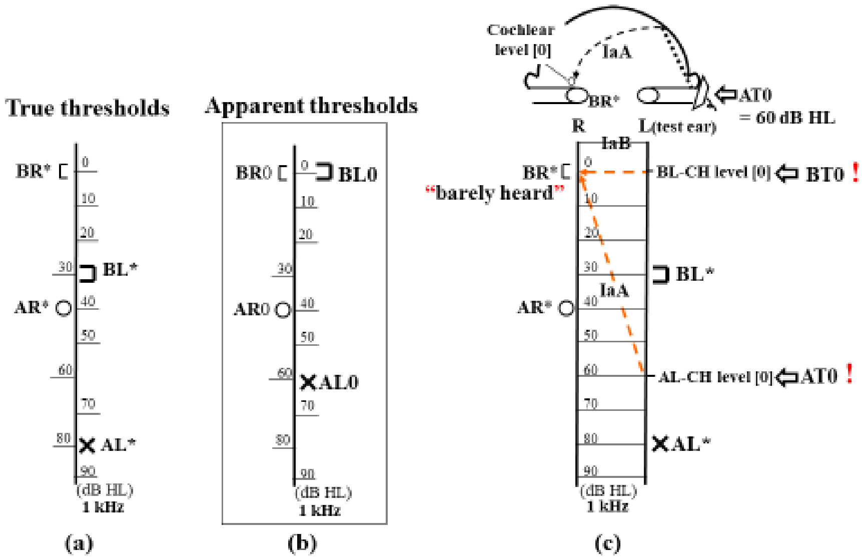


Figure 3-1 Audiometric configuration at 1000 Hz without masking

< Findings of the configuration without masking >

1) The apparent BC thresholds (BR0, BL0) are the true thresholds for at least one ear.
   (Both BR0 and BL0 cannot be SH thresholds at the same time.)
2) The apparent AC threshold in the better ear (AR0) is always the true threshold.
   (AR0 cannot be the SH threshold. This will be discussed in detail in Lecture 4.)
3) The apparent AC threshold in the poorer ear (AL0) is either the true or SH threshold.
4) If AL0 is the SH threshold, IaA is 60 dB (= AL0 − BR0).

Therefore, considering the possibility that AL0 could be the SH threshold, we should retest the AC threshold in the left (test) ear with masking in the right ear. Noises higher than 40 dB HL (N > [AR*]) elevate the BC threshold in the right (non-test) ear; i.e., effective masking (cf. **2.2-1**), while masking noises lower than or equal to 40 dB HL (N $\le$ [AR*]) do not elevate that BC threshold; i.e., ineffective masking.

In this lecture series, the right and left sides are represented as Rt and Lt, respectively. For example, Rt N is noise presented to the right ear. Note that in the operation of levels and quantities (amounts), each term of equality and inequality is represented as a numerical value (cf. **2.4 [1]**).

**** Further note ****

*) The apparent thresholds are measured without masking.

*) In **Fig. 3-1(b)**, the apparent AB gap in the right ear (GR0 = AR0 − BR0) is a true AB gap (GR0 = GR*) because the apparent AC and BC thresholds in the right ear are the true thresholds (AR0 = AR*, BR0 = BR*). By contrast, the apparent AB gap in the left ear (GL0 = AL0 − BL0) is a false AB gap because the apparent AC and BC thresholds in the left ear are the SH thresholds.

*) Nn is the n-th masking noise.

3.1-2 The plateau method: a masking procedure for air conduction

(1) 40 dB HL < Rt N < 60 dB HL [Undermasking]

As shown in **Fig. 3-2**, when the masking noise level in the right (non-test) ear (Rt Nn) is increased from 45 dB HL in 5 dB-steps, the AC threshold levels measured in the left (test) ear are likewise increased in direct proportion. Since AL0 is the SH threshold, IaA is 60 dB. Accordingly, we will now consider what happens at the level of the cochleae.

When **Rt N1 = 50 dB HL** (α1 = 10 dB) (**Fig. 3-3**), let us check the following three key points.

First, **a)** Consider whether N1 causes overmasking (OM) (**Fig. 3-3 [a]**). The OM level of N1 (OM level [1]) is as follows:

OM level [1] = N2 − IaA = 50 (dB HL) − 60 (dB)
= −10 dB HL (< BL* = 30 dB HTL).

Since the OM level [1] is lower than the true BC threshold level in the test ear (BL* of 30 dB HTL), N1 does not cause OM.

Second, **b)** Consider how many decibels of the test signal will be barely heard by the participant (**Fig. 3-3 [b]**). The BC threshold of the non-test ear masked by N1 (mBR[1]) and its AL-CH level [1] are determined as follows:

mBR[1] = BR* + α1 = 0 (dB HTL) + 10 (dB)
= 10 dB THL.

AL-CH level [1] = mBR[1] + IaA = 10 (dB THL) + 60 (dB)
= 70 dB HL (< AL* = 80 dB HTL).

Here, when AT1 of 70 dB HL is delivered to the test ear, it is not received by the test inner ear because the AT1 level is lower than the true AC threshold level in the test ear (AL* of 80 dB HTL). In contrast, the AT1 cochlear level in the non-test ear is as follows:

Rt cochlear level [AT1] = AT1 − IaA = 70 (dB HL) − 60 (dB)
= 10 dB HL (= mBR[1] = 10 dB HTL).

In this case, the AT1 is just audible in the non-test inner ear (mBR[1]) and is not received by the test inner ear (BL*). Hence, the AT1 hearing is SH and the AC threshold measured in the test ear with N1 (AL1) of 70 dB HTL is the SH threshold (SHT) for AC.

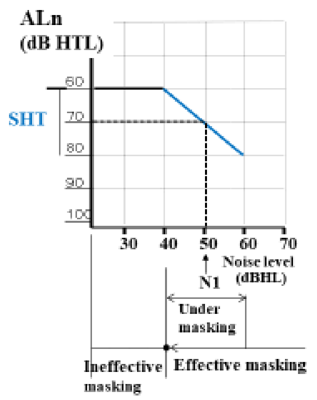


Figure 3-2 Undermasking 1

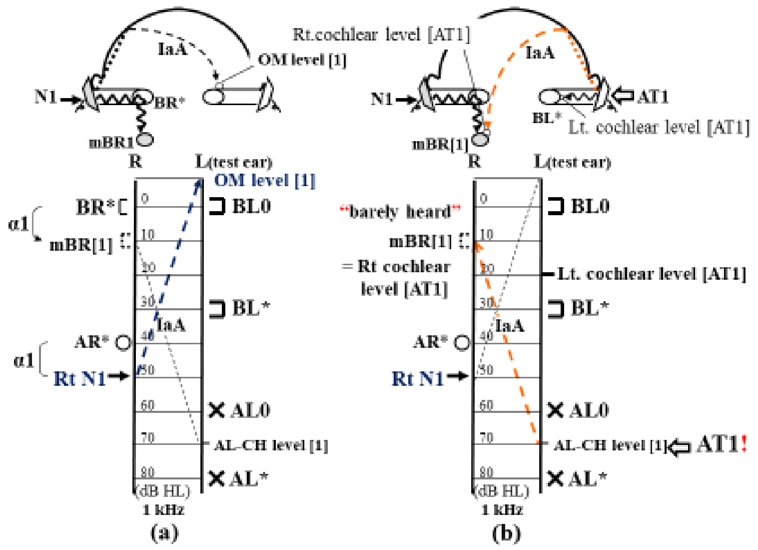


Figure 3-3 Undermasking 2

Third, c) Since the noises at these levels (40 dB HL < Rt N < 60 dB HL) are insufficient to prevent SH of the AC test signals, masking with these noises is termed undermasking. At that point, the test signals (60 dB HL < AT < 80 dB HL) are received by the masked BC threshold in the non-test ear (mBR[n]). As a result, if the noise level is increased by 10 dB, mBR[n] is also elevated by the same amount. This means that the AC threshold measured in the test ear is also elevated by 10 dB, exhibiting a direct proportional relationship to the noise levels (**Fig. 3-2**).

**** Further note ****

) The cochlear level of AT1 in the left ear (Lt cochlear level [AT1] = 20 dB HL) is lower than BL (= 30 dB HTL). Therefore, the AT1 is not heard by the left inner ear (BL*).

(2) 60 dB HL ≤ Rt N ≤ 90 dB HL [Adequate masking]

As in **Fig. 3-4**, when noises at levels from 60 to 90 dB HL are introduced to the right (non-test) ear, the AC thresholds measured in the left (test) ear with masking remain the same at 80 dB HTL, thus indicating a masking plateau. When N2 is 60 dB HL and N4 is 90 dB HL, masking with these noise levels will produce interesting results, as will be described later.

When **Rt N3 = 75 dB HL** (α3 = 35 dB) (**Fig. 3-5 [a]**),

OM level [3] = N3 − IaA = 75 (dB HL) − 60 (dB)
= 15 dB HL (< BL* = 30 dB HTL).

a) Since the OM level [3] is lower than the true BC threshold level in the test ear (BL*), N3 does not cause OM. Then, the BC threshold of the non-test ear masked by N3 (mBR[3]) and its AL-CH level are as follows:

mBR[3] = BR* + α3 = 0 (dB HTL) + 35 (dB)
= 35 dB THL.

AL-CH level [3] = mBR[3] + IaA = 35 (dB THL) + 60 (dB)
= 95 dB HL (> AL* = 80 dB HTL).

b) When AT3 of 80 dB HL is presented to the test ear (**Fig. 3-5 [b]**),

Lt cochlear level [AT3] = AT3 − GL* = 80 (dB HL) − 50 (dB)
= 30 dB HL (= BL* = 30 dB HTL).

Therefore, the test signal is barely heard by the test inner ear (BL*). In contrast,

Rt cochlear level [AT3] = AT3 − IaA = 80 (dB HL) − 60 (dB)
= 20 dB HL (< mBR[3] = 35 dB HTL).

It is not heard by the non-test inner ear (mBR[3]). Hence, the AT3 hearing is true, and then the AC threshold measured in the test ear with N3 (AL3) of 80 dB HTL is a true AC hearing threshold (i.e., AL3 = AL*).

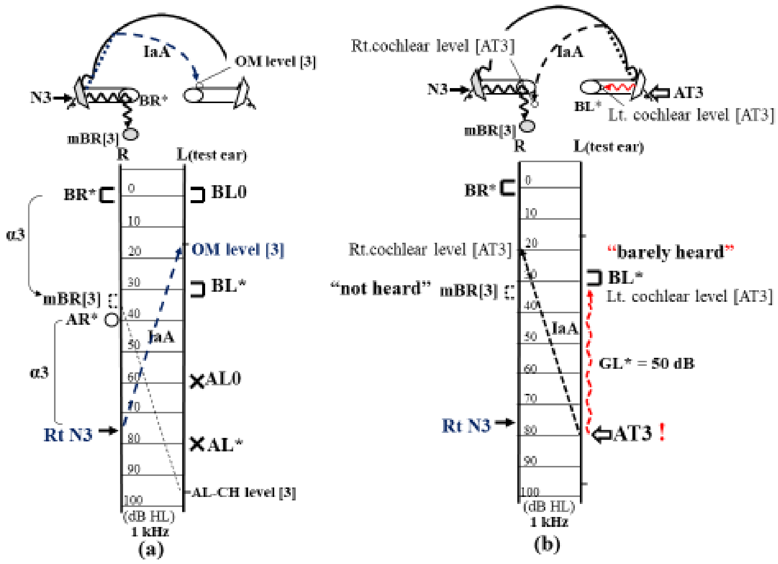


Figure 3-4 Adequate masking 1

c) Since noises at these levels (60 dB HL ≤ Rt N ≤ 90 dB HL) are sufficient to prevent SH of AC test signals and do not cause OM, this is termed adequate masking (**Fig. 3-5**).

In adequate masking, the AC test signal of 80 dB HL is heard by the test ear's true BC threshold (BL*), therefore, the AC thresholds measured in the test ear remain stable even if the noise levels are increased or decreased within these levels (60 dB HL ≤ Rt N ≤ 90 dB HL).

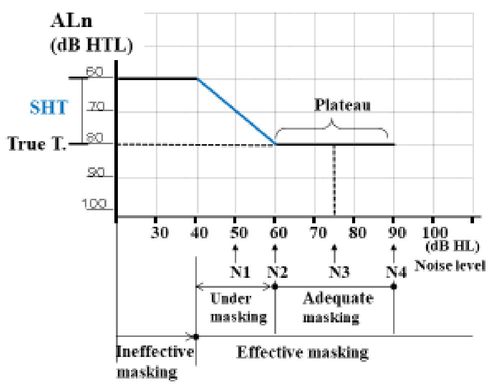


Figure 3-5 Adequate masking 2

(3) 90 dB HL < Rt N [Overmasking]

When noise levels are higher than 90 dB HL, the AC thresholds measured in the left (test) ear are elevated again in direct proportional manner (**Fig. 3-6**).

When **Rt N5 = 100 dB HL** (α5 = 60 dB) (**Fig. 3-7**),

OM level [5] = N5 − IaA = 100 (dB HL) − 60 (dB)
= 40 dB HL (> BL* = 30 dB HTL).

a) Since the OM level [5] is higher than BL*, N5 causes OM. That is, the BC threshold in the test ear is elevated. Depending on the boundary condition for OM (cf. **2.3-2**), the BC threshold level of the test ear overmasked by N5 (omBL[5]) is equal to the OM level [5]:

omBL[5] = 40 dB HTL = (OM level [5] = 40 dB HL).

Otherwise, the amount of the test ear's BC threshold elevation with N5; i.e., the amount of OM with N5 (OMA5) is the difference between the OM level [5] and BL*, and is equal to the effective amount of OM with N5 (β5) (cf. **2.3-1**):

OMA5 = OM level [5] − BL* = 40 (dB HL) − 30 (dB HTL)
= 10 dB (= β5)

Therefore, omBL[5] is as follows:

omBL[5] = BL* + β5 = 30 (dB HTL) + 10 (dB)
= 40 dB HTL.

The AC threshold of the test ear overmasked by N5 (omAL[5]) is as follows:

omAL[5] = AL* + β5 = 90 dB HTL.

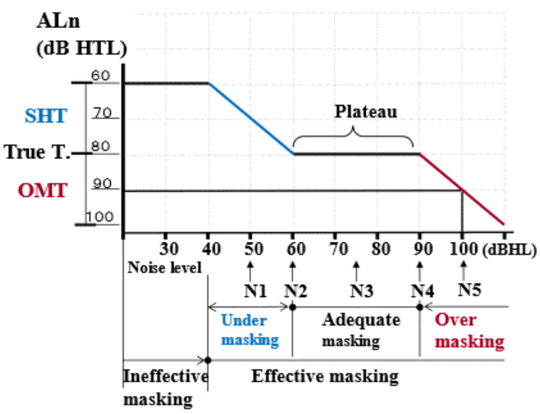


Figure 3-6 Overmasking 1

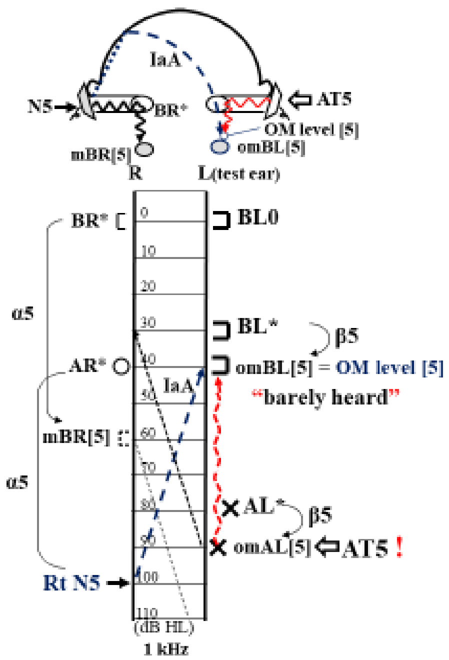


Figure 3-7 Overmasking 2

b) When AT5 of 90 dB HL is presented to the test ear (**Fig. 3-7**),

Lt cochlear level [AT5] = AT5 − GL* = 90 (dB HL) − 50 (dB)
= 40 dB HL (= omBL[5] = 40 dB HTL).

The AT5 is barely heard by the test inner ear (omBL[5]). Hence, the AT5 hearing is overmasked, and the AC threshold measured in the test ear with N5 (AL5) of 90 dB HTL is equal to the test ear's AC threshold overmasked by N5 (i.e., AL5 = omAL[5]). AL5 is an overmasked hearing threshold (OMT). By contrast,

Rt cochlear level [AT5] = AT5 − IaA = 90 (dB HL) − 60 (dB)
= 30 dB HL (< mBR[5] = 60 dB HTL).

It is not received by the non-test inner ear (mBR[5]). In overmasking, it does not matter whether the test signal is heard by the non-test ear.

c) Since noises at these levels (90 dB HL < Rt N ≤ 110 dB HL) elevate the BC threshold in the test ear, OM occurs (**Fig. 3-6**). In OM, the AC test signals (80 dB HL < AT ≤ 100 dB HL) are heard by the test ear's BC threshold overmasked by Nn (omBL[n]), therefore, the shift amounts of the AC threshold levels measured in the test ear are proportional to those of noise levels in the same manner as in undermasking.

**** Further note ****

*) In Lecture 3, the maximum output level of the masking noise at 1000 Hz is assumed to be 110 dB HL.

(4) The minimum and maximum adequate masking noise levels

The minimum noise level for adequate masking is referred to as the minimum adequate masking noise level (Nmin). Nmin for AC is described as ANmim. The maximum noise level for adequate masking is referred to as the maximum adequate masking noise level (Nmax). In cases where masking plateaus are present, Nmax is equal to the maximum level of masking noise at which OM does not occur (MN) (cf. **2.3-3** **[2]**). Nmax and MN are the same level for both AC and BC (cf. **Fig. 2-16**).

When **Rt N2 = 60 dB HL** (α2 = 20 dB) **[Minimum adequate masking]** (**Fig. 3-8**),

OM level [2] = N2 − IaA
= 60 (dB HL) − 60 (dB)
= 0 dB HL
(< BL* = 30 dB HTL).

a) N2 does not cause OM to occur. Then,

mBR[2] = BR* + α2 = 0 (dB HTL) + 20 (dB)
= 20 dB THL.

AL-CH level [2] = mBR[2] + IaA
= 20 (dB THL) + 60 (dB)
= 80 dB HL
(= AL* = 80 dB HTL).

b) When AT2 of 80 dB HL is presented to the left (test) ear,

Lt cochlear level [AT2] = AT2 − GL*
= 80 (dB HL) − 50 (dB)
= 30 dB HL
(= BL* = 30 dB HTL).

Therefore, the AT2 is barely heard by the test inner ear (BL*). In contrast,

Rt cochlear level [AT2] = AT2 − IaA
= 80 (dB HL) − 60 (dB)
= 20 dB HL
(= mBR[2] = 20 dB HTL).

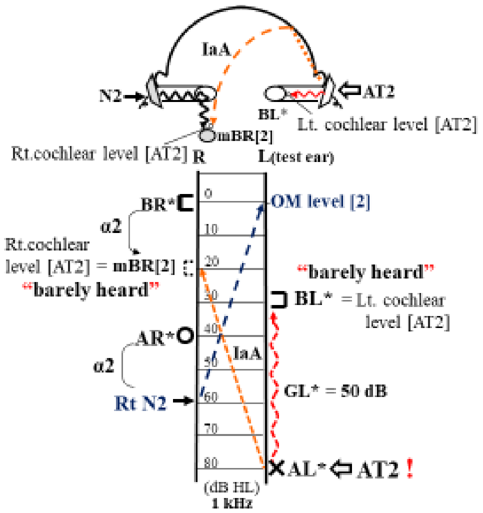


Figure 3-8 Minimum adequate masking for AC

Note that AT2 is also barely heard by the right (non-test) inner ear (mBR[2]). Thus, the test signal is barely being heard by both the test and non-test inner ears at the same time. Then, is this hearing true, shadow, or cross hearing?

Since AT2 is heard by the true BC threshold in the test ear, it is true hearing and the test AC threshold measured in the test ear with N2 (AL2) of 80 dB HTL is the true AC threshold. It should be noted that AT2 hearing by the non-test ear is cross hearing, not SH (cf. **2.1-1**), and that N2 is the minimum adequate masking noise level for AC (ANmim).

Based on discussion above, true hearing is defined as the hearing of the test signals by the test inner ear (i.e., the true BC threshold in the test ear), regardless of whether they are heard by the non-test ear or not. Additionally, when OM occurs, test signals are heard by the test ear (i.e., the overmasked BC threshold in the test ear). It is false hearing due to OM (**Table 3-1**).

Table 3-1 Hearing of the test signals

	Non-test (right) ear	Test (left) ear
Undermasking	heard by the masked BC threshold	not heard
Adequate masking	no matter	heard by the true BC threshold
Overmasking	no matter	heard by the overmasked BC threshold

**** Further note ****

*) When no plateau presents, Nmax is not equal to MN (cf. **Fig. 3-14**).

*) Cros-hearing is defined as the hearing of the signals (test signals or noises) presented to one ear by the opposite ear, regardless of whether they are heard by the ear to which they are presented (cf. **2.1-1**).

*) Shadow hearing is defined as the hearing of the test signals by the non-test ear not by the test ear.

When **Rt N4 = 90 dB HL**, (α4 = 50 dB); **[Maximum adequate masking]** (**Fig. 3-9**)

OM level [4] = N4 − IaA

= 90 (dB HL) − 60 (dB)

= 30 dB HL

(= BL* = 30 dB HTL).

N4 is barely heard by the left (test) inner ear (BL*).

Here, when AT4 of 80 dB HL (= AL*) is presented to the test ear,

Lt cochlear level [AT4] = AT4 − GL*

= 80 (dB HL) − 50 (dB)

= 30 dB HL

(= OM level [4]).

Depending on the boundary condition for OM, the AT4 is barely heard by the test inner ear (BL*): N4 does not cause OM. N4 is the maximum adequate masking noise level (Nmax) and is equal to the maximum level of masking noise at which OM does not occur (MN):

Rt N4 = Rt Nmax = Rt MN = BL* + IaA.

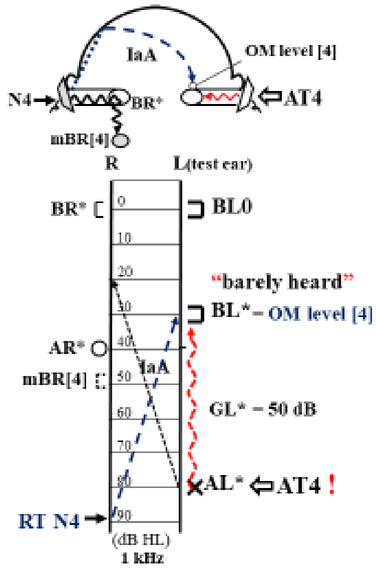


Figure 3-9 Maximum adequate masking for AC

(5) The air-conduction plateau width

Fig. 3-10 shows a case in which the typical plateau for AC is present. SH of the AC test signals occurs when no masking, ineffective masking or undermasking is present. When masking is absent or ineffective, the test signals are heard by the true BC threshold in the non-test ear (BR*), whereas in undermasking, they are heard by the masked BC thresholds of the non-test ear (mBR[n]).

When masking is adequate, test signals are audible by the true BC threshold in the test ear (BL*), therefore, the measured AC thresholds remain stable even if the noise levels are increased or decreased within the range from 60 to 90 dB HL. That is, the plateau has been reached. In overmasking, the signals are received by the overmasked BC threshold in the test ear (omBL[n]).

A plateau width (PW) is defined as the difference between the maximum adequate masking noise level in the right ear (Rt Nmax) and the minimum adequate masking noise level in the right ear (Rt Nmin). In other words, the PW is the noise level range in which adequate masking can be performed. The AC plateau width of the left ear (Lt APW) is described in **Fig. 3-10** and through the following formula:

Lt APW = Rt Nmax – Rt ANmin.

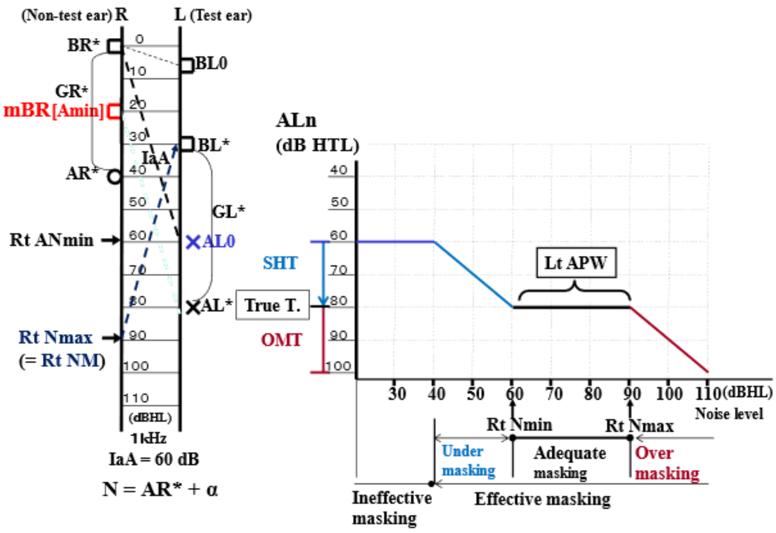


Figure 3-10 Typical AC plateau width

**** Further note ****

*) When plateaus are absent, Nmax is not present. However, MN is sometimes present (cf. **3.5** **[2]**). Therefore, we must define them separately.

3.2 Bone-conduction audiometry

The plateau method for BC audiometry is fundamentally the same as the one used for AC. The difference lies in the amount of the interaural attenuation. The BC plateau width of the left ear (Lt BPW) is described below:

Lt BPW = Rt Nmax – Rt BNmin.

Let us consider the audiometric configuration at 1000 Hz as follows:

	Non-test (right) ear	Test (left) ear	Interaural attenuation
Bone conduction	BR* = 0 dB HTL	BL* = 30 dB HTL	IaB = 0 dB or 5 dB
Air conduction	AR* = 40 dB HTL	AL* = 80 dB HTL	IaA = 60 dB
Air-bone gap	GR* = 40 dB	GL* = 50 dB	

(1) Lt BPW with the IaB value of 0 dB

Figure 3-11 shows the typical BPW with the IaB value of 0 dB.

When Rt N1 = 50 dB HL ($\alpha 1$ = 10 dB), the BC threshold measured in the left ear with N1 (BL1) is 10 dB HTL and is the SH threshold. At this point, the above noise level results in undermasking.

When Rt N2 = 80 dB HL ($\alpha 2$ = 40 dB), BL2 of 30 dB HTL is obtained as the true threshold and adequate masking is produced.

When Rt N3 = 100 dB HL ($\alpha 3$ = 60 dB), BL3 is 40 dB HTL, which is the OM threshold, thereby resulting in OM.

As shown in **Fig.3-12**, Rt N of 70 dB HL (α = 30 dB) is the minimum adequate masking noise level for BC in the right ear (Rt BNmin) because the CH level of Rt BNmin in the left ear (BL-CH level [Bmin]) is the same level as BL* shown as follows:

mBR[Bmin] = BR* + α = 0 (dB HTL) + 30 (dB)
= 30 dB THL.

BL-CH level [Bmin] = mBR[BNmin] + IaB
= 30 (dB HTL) + 0 (dB)
= 30 dB HL (= BL* = 30 dB HTL).

The maximum adequate masking noise level in the right ear (Rt Nmax) is the same level for both AC and BC. Since Rt Nmax is 90 dB HL,

Lt BPW = Rt Nmax − Rt BNmin
= 90 (dB HL) − 70 (dB HL)
= 20 dB.

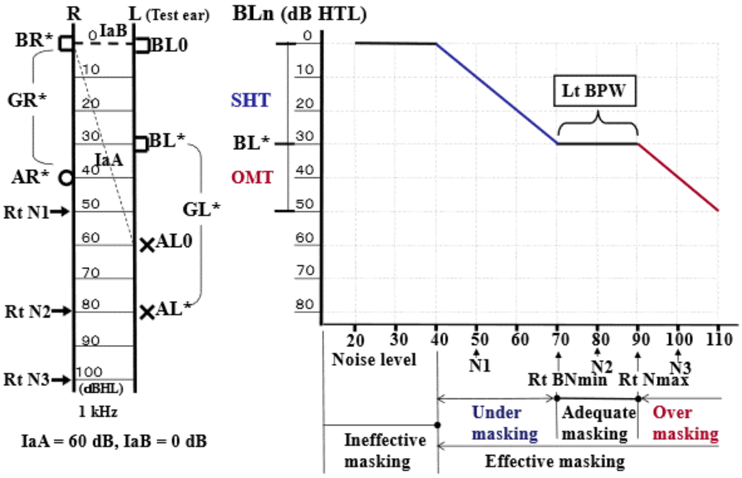


Figure 3-11 Typical BC plateau width with IaB of 0 dB

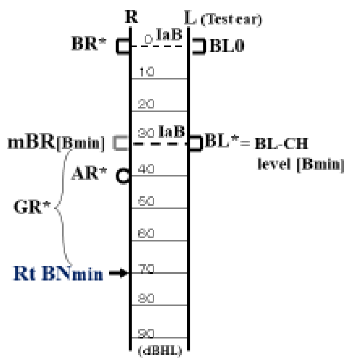


Figure 3-12 Rt BNmin

**** Further note ****

*) In principles, the bone vibrator is placed at the mastoid in this lecture.

*) Studbaker (1964) discussed plateau graphs in greater depth and detail.

(2) Lt BPW with the IaB value of 5 dB

Fig. 3-13 shows the typical PW for BC with the IaB value of 5 dB. As in **Fig. 3-14**, when the IaB value is 5 dB, Rt BNmin is 65 dB HL (α = 25 dB). The CH level of Rt BNmin in the left ear is the same level as BL* as follows:

mBR[Bmin] = BR* + α = 0 (dB HTL) + 25 (dB)
= 25 dB THL.

BL-CH level [Bmin] = mBR[BNmin] + IaB
= 25 (dB HTL) + 5 (dB)
= 30 dB HL (= BL* = 30 dB HTL).

Since Rt Nmax is 90 dB HL,

Lt BPW = Rt Nmax − Rt BNmin
= 90 (dB HL) − 65 (dB HL)
= 25 dB.

Note that the Lt BPW becomes wider by the amount of the IaB value.

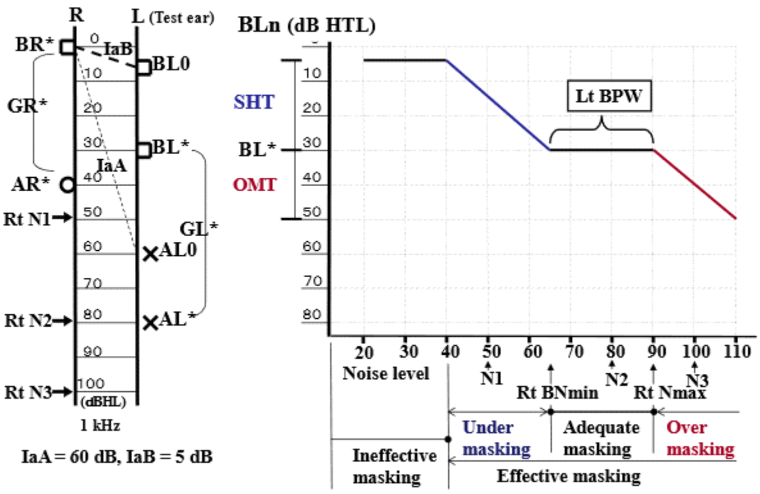


Figure 3-13 Typical BC plateau width with IaB of 5 dB

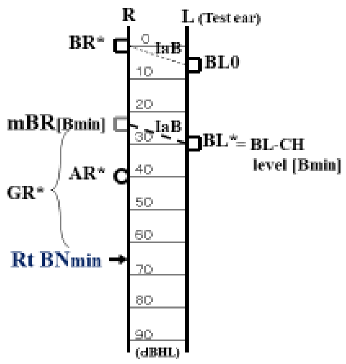


Figure 3-14 Rt BNmin

3.3 Clinically significant plateau widths

Although a PW of 5 dB is theoretically significant (**Fig. 3-15 [a]**), clinically **we** are unable to detect such a narrow plateau as 5-dB in width. In this lecture series, we assume that the PWs of ≥ 15 dB for both AC and BC are clinically significant to ensure a wide safety margin (**Fig. 3-15 [c]**). Note that a PW of 10 dB might be significant if it could be obtained with high measurement accuracy (**Fig. 3-15 [b]**).

As shown in **Fig. 3-13**, when a typical plateau (Lt BPW = 25 dB) is obtained, it stipulates that "a clinically significant plateau can be identified." If a BPW of 5 dB is obtained, "a clinically significant plateau cannot be identified."

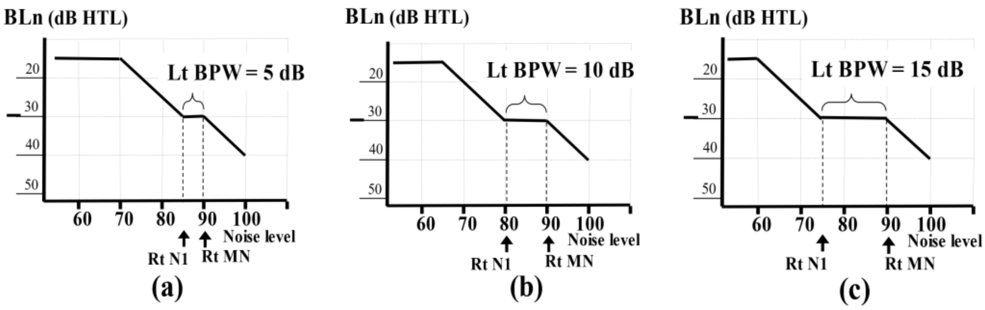


Figure 3-15 Significant BC plateau widths

**** Further note ****

*) The IaB value should be assumed to be 0 dB if we put the conditions of shadow hearing first. However, this is not always true. Clinically, only 5 dB of IaB has meanings for the decision of the true BC thresholds (cf. **Supplement 6**).

3.4 Masking plateau widths

From the typical example above (cf. **Fig. 3-1**), let us obtain the AC and BC plateau widths of the left ear (Lt APW, Lt BPW). Here, the left ear is the test, poorer ear by AC. In cases with typical plateaus, the Nmax presented to the right, non-test ear (Rt Nmax) is equal to Rt MN (the maximum level of masking noise at which OM does not occur in the right ear). Note that Rt Nmax and Rt MN are the same level for both AC and BC.

Rt Nmax = Rt MN = BL* + IaA --- (1)

(1) The air-conduction plateau width of the left ear: Lt APW

Lt APW = Rt Nmax − Rt ANmin.

When the minimum adequate masking noise for AC (ANmin) is introduced to the right ear, its CH level for AC in the left ear (AL-CH level [Amin]) is as follows (**Fig. 3-16**):

AL-CH level [Amin] = mBR[Amin] + IaA

= (Rt ANmin − GR*) + IaA

This level is equal to the true AC threshold level in the left ear (AL*):

(Rt ANmin − GR*) + IaA = AL*

∴ Rt ANmin = AL* − IaA + GR* --- (2)

Subtract equation (2) from equation (1).

Lt APW = Rt Nmax – Rt ANmin

= (BL* + IaA) − (AL* − IaA + GR*)

= IaA − GR* + IaA − (AL* − BL*)

∴ Lt APW = (IaA − GR*) + (IaA − GL*) --- (3)

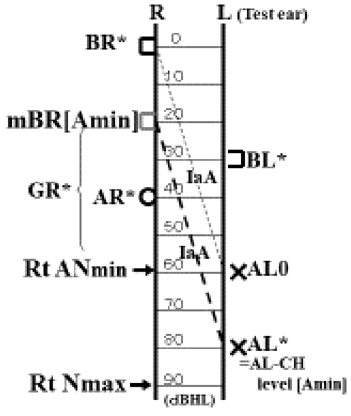


Figure 3-16 Lt APW

In **Fig. 3-17**, Lt APW is calculated as follows:

Lt APW = (IaA − GR*) + (IaA − GL*)

= {60 (dB) − 40 (dB)} + {60 (dB) − 50 (dB)}

= 30 dB.

Additionally, if Equation (3) is expressed as follows:

Lt APW = 2IaA − GR* − GL*,

the meaning of the equation would be lost.

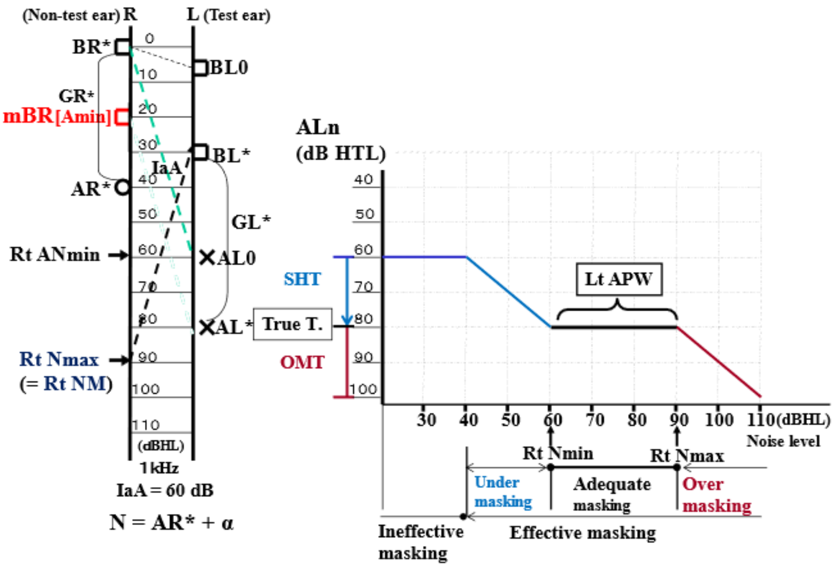


Figure 3-17 Typical AC plateau width

**** Further note ****

*) From equation (3), we find that AB gaps at some frequency are never larger than the IaA value at that frequency. If AB gaps were larger than IaA, the sign of plateau widths would be negative and a paradox would occur (cf. **Supplement 3**).

(2) The bone-conduction plateau width of the left ear: Lt BPW

Lt BPW = Rt Nmax – Rt BNmin.

Lt BPW can be treated equally with AC. When the minimum adequate masking noise for BC (BNmin) is introduced to the right ear, its BL-CH level is as follows (**Fig. 3-18**):

BL-CH level [Bmin] = mBR[Bmin] + IaB

= (Rt BNmin − GR*) + IaB

This level is equal to the true BC threshold level in the left, test ear (BL*):

(Rt BNmin − GR*) + IaB = BL*

∴ Rt BNmin = BL* − IaB + GR* - - - (4)

Subtract equation (4) from equation (1).

Lt BPW = Rt Nmax − Rt BNmin

= (BL* + IaA) − (BL* − IaB + GR*)

∴ Lt BPW = (IaA − GR*) + IaB - - - (5)

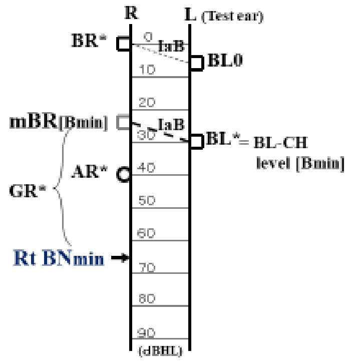


Figure 3-18 Rt BNmin

In **Fig. 3-19**, the IaB value is 5 dB and Lt BPW is as follows:

Lt BPW = (IaA − GR*) + IaB

= {60 (dB) − 40 (dB)} + 5 (dB)

= 25 dB.

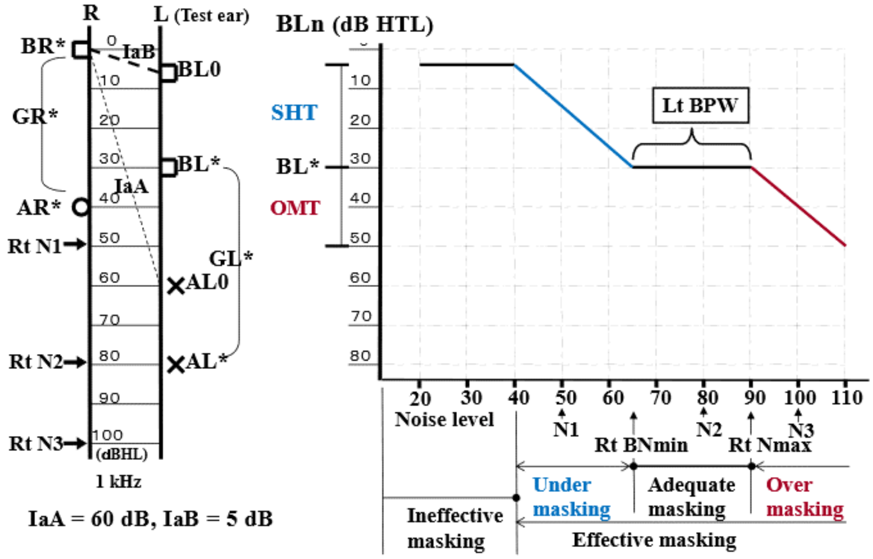


Figure 3-19 Typical BC plateau width

If the left ear is the poorer ear by AC (AR0 < AL0), typical PWs for AC and BC of the left ear (Lt APW, Lt BPW) can be written as follows:

Lt APW = (IaA − Rt true AB gap) + (IaA − Lt true AB gap) - - - (3’)

Lt BPW = (IaA − Rt true AB gap) + IaB - - - (5’)

If these equations were applied to all audiometric configurations, the results would be elegant. General equations will be discussed in Lecture 7.

Depending on equation (3’), if bilateral true AB gaps are equal to IaA (GR* = GL* = IaA), then Lt APW = 0 dB and the true AC threshold in the left ear cannot be determined.

Depending on equation (5’), if the true AB gap of the right ear is equal to IaA (GR* = IaA) and IaB = 0 dB, then Lt BPW = 0 dB and the true BC threshold in the left ear cannot be established.

Therefore, to comprehend masking systematically, AC and BC should be treated equally in both theoretical and clinical environments.

3.5 Specific cases

(1) Atypical plateau cases

Fig. 3-20 shows an atypical plateau case for AC in which no noise levels of undermasking are present. First, the right ear is masked and AC thresholds in the left ear are measured.

When Rt N > 40 dB HL (= AR*), these noise levels provide effective masking. A noise of 60 dB HL presented to the right ear is the maximum level of masking noise at which OM does not occur (Rt MN = 60 dB HL) and is likewise the maximum adequate masking noise level (Rt Nmax):

Rt MN = Rt Nmax = 60 dB HL.

Therefore, when 40 dB HL < Rt N ≤ 60 dB HL, adequate masking is provided, and the AC thresholds measured in the left ear with masking (60 dB HTL) are true thresholds.

In this case, the minimum adequate masking noise level for AC in the right ear (Rt ANmin) is either not present or cannot be defined because masking with a noise of 40 dB HL is ineffective. Therefore, in atypical plateau cases, the noise level equal to the true AC threshold level in the non-test ear (AR*) is used instead of Rt ANmin to represent the AC plateau widths. An alternative noise in the right ear (Rt N0) is written by

Rt N0 = [AR*] = 40 dB HL.

An atypical plateau width for AC of the left ear (Lt APW) is as follows:

Lt APW = Rt Nmax − Rt N0
= Rt MN − [AR*] = 60 (dB HL) − 40 (dB HL)
= 20 dB.

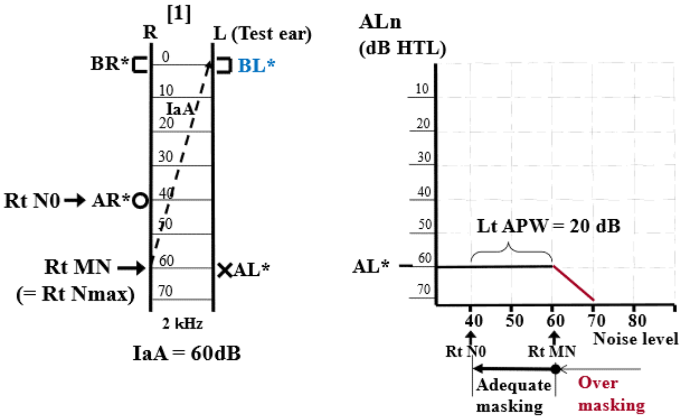


Figure 3-20 Atypical AC plateau width

Subsequently, for BC, Rt BNmin is also not present (**Fig. 3-21**) and Lt BPW is as follows:

Lt BPW = Rt Nmax − Rt N0
= Rt NM − [AR*] = 60 (dB HL) − 40 (dB HL)
= 20 dB.

Atypical plateaus will be discussed more in depth in Lecture 7 (cf. **7.1** **[2]**).

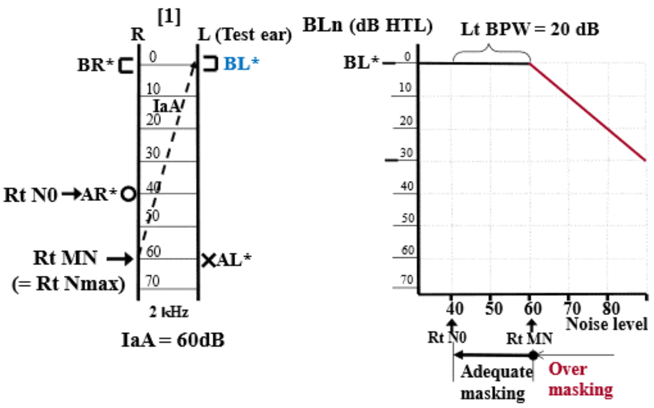


Figure 3-21 Atypical BC plateau width

**** Further note ****

*) In actuality, the cases of atypical plateaus are larger in number than those of typical plateaus.

(2) No plateau cases

Two no-plateau cases are presented below.

a) Overmasking

The configuration in **Fig.3-22** shows that the true AB gaps in both ears are equal to IaA and the true hearing thresholds of both ears are the same level. When Rt N > 60 dB HL, the BC thresholds in the right ear are elevated (mBR[n] > BR*; i.e., effective masking). At the same time, the noises of these levels always cause OM, and the AC and BC thresholds measured in the left ear with Nn (ALn, BLn) are the OM thresholds. Therefore, no AC or BC plateaus are present. Naturally, Rt Nmax is not present. However, note that the maximum level of masking noise at which OM does not occur in the right ear (Rt MN = 60 dB HL) is present.

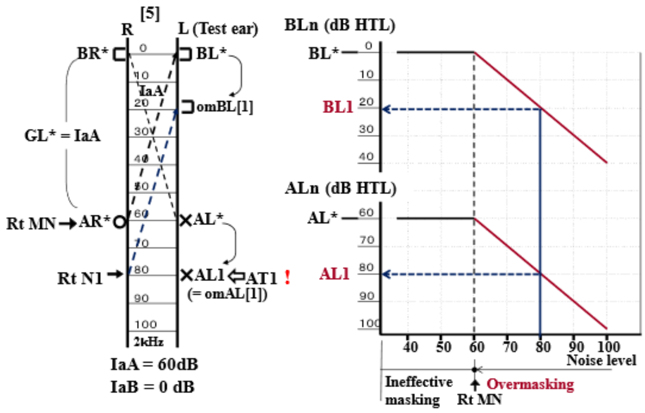


Figure 3-22 No plateau case 1: overmasking

b) Undermasking

The configuration in **Fig.3-23** illustrates that the true AB gap of the right ear is equal to IaA and the left ear is completely deaf. When Rt N > 60 dB HL, masking with these noises is effective. Simultaneously, noises at these levels always cause undermasking to occur and the AC and BC thresholds measured in the left ear with masking are always the SH thresholds. Therefore, AC and BC plateaus are not present. Note that Rt MN, Rt Nmax and Rt Nmin are all not present.

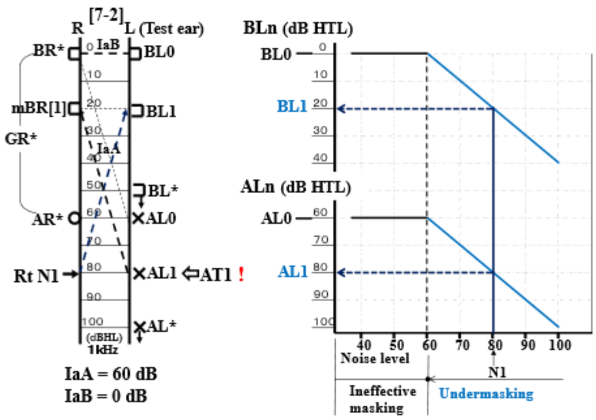


Figure 3-23 No plateau case 2: undermasking

Cases in which "the clinically significant plateau cannot be identified" includes the following:
1) Cases in which the plateaus are not present (**Fig. 3-22**, **3-23**)
2) Cases in which, even if a 0 dB plateau is present, it cannot be identified (cf. **6.4-2 [1]**)
3) Cases in which, even if the plateaus are present (i.e., PW = 5 dB or 10 dB), they are clinically difficult to identify (cf. **Fig. 3-15**)

**** Further note ****

*) In **Fig. 3-22**, when N1 of 80 dB HTL is presented to the right ear (Rt N1 = 80 dB HTL), OM occurs. AT1 of 80 dB HL is barely heard by both inner ears (omBL[1] = 20 dB HL, mBR[1] = 20 dB HL). The hearing of AT1 is at once an overmasked hearing and a cross one. It is not shadow hearing (cf. **Fig. 6-18**).

*) The configuration in **Fig. 3-22** is a pattern [5], and that in **Fig. 3-23** is a pattern [7-2], as is described in Lecture 4.

3.6 Summary of Lecture 3

1. The configurations with the typical AC and plateaus were discussed. To simplify the discussion, it is assumed that the right ear is the non-test, better ear by AC (masked ear) and the left ear is the test, poorer ear by AC.

a) In undermasking, the test signals are heard by the masked BC threshold in the non-test ear (mBR[n]) and are not received by the true BC threshold in the test ear. The hearing of the test signals is SH and the measured thresholds are the SH thresholds. The shift amounts of the AC and BC threshold levels measured in the test ear are proportional to those of noise levels.

b) In adequate masking, the test signals are heard by the true BC threshold in the test ear (BL*). The hearing of the test signals is true hearing and the measured thresholds are the true thresholds. Even if the noise levels are increased or decreased, the AC and BC threshold levels measured in the test ear remain stable.

c) In overmasking, the test signals are heard by the overmasked BC threshold in the test ear (omBL[n]). The hearing of the test signals is overmasked hearing and the measured thresholds are the overmasked thresholds. The shift amounts of the AC and BC threshold levels measured in the test ear are proportional to those of noise levels.

2. When masking with the minimum adequate masking noise (Nmin), the test signal is barely heard by both the test and non-test inner ear at the same time. The hearing of the test signal is true hearing and not SH. True hearing is defined as the hearing of test signals by the test ear (i.e., the true BC threshold in the test ear), regardless of whether they are heard by the non-test ear or not.

3. In cases with typical plateaus, the maximum adequate masking noise level (Nmax) is equal to the maximum level of masking noise at which OM does not occur (MN).

Nmax = MN = the true BC threshold in the test ear + IaA.

4. When the apparent AC and BC thresholds in the left ear are SH thresholds (i.e., typical plateau cases), the plateau widths of the left ear (Lt. APW, Lt. BPW) are as follows:

Lt APW = Rt Nmax − Rt ANmin = (IaA − GR*) + (IaA − GL*),

Lt BPW = Rt Nmax − Rt BNmin = (IaA − GR*) + IaB,

where GR* and GL* are the true AB gap of the right and left ear, respectively.

5. In this lecture series, it is assumed that the PWs of ≥15 dB for both AC and BC are clinically significant.

Cases in which "the clinically significant plateau cannot be found" includes the following:

1) Cases in which the plateaus are not present
2) Cases in which, even if a 0 dB plateau is present, it cannot be identified (PW = 0 dB)
3) Cases in which, even if the plateaus are present (PW = 5 dB or 10 dB), they are clinically difficult to identify

6. The plateaus of the left ear are classified into 3 cases as follows:

1) Typical plateau cases: Rt MN = Rt Nmax, and Rt Nmin is present.
2) Atypical plateau cases: Rt MN = Rt Nmax, and Rt Nmin is not present.
3) No plateau cases: the adequate masking noises are not present. Masking noises always cause overmasking or undermasking.

Lecture 4 Implications of the relationship AB gap ≤ IaA

When AC test signals are introduced into one ear using supra-aural earphones, the converted BC signals generated by the output of the earphones reach the cochlea of the same side as well as the opposite side. Participants cannot discriminate the converted BC signals from the AC test signals (cf. **1.4**). Therefore, AB gaps are never larger than the interaural attenuation for AC signals (IaA):

AB gap ≤ IaA.

Three implications that can be drawn from this relationship are summarized as follows:

1. Estimation of the true BC threshold range in the test ear
2. Requirements for apparent thresholds to be SH thresholds.
3. Patterns of audiometric configurations at a given frequency

From these implications, criteria for masking are considered.

This lecture is a highlight and the most important of all the lectures.

4.1 Estimation of the true BC threshold range in the test ear

(1) An audiogram with SH thresholds
(2) Cause and effect
(3) The minimum level of the true BC threshold possible in the test ear

4.2 Requirements for apparent thresholds to be the SH thresholds

(1) Cases in which bilateral true BC thresholds are equal (i.e., BR* = BL*)
(2) Cases in which bilateral true BC thresholds differ (e.g., BR* < BL*)
(3) Cases in which bilateral apparent AC thresholds differ (e.g., AR0 < AL0)
(4) The requirements for SH thresholds

4.3 Patterns of audiometric configurations at a given frequency

(1) Patterns where bilateral apparent AC thresholds differ significantly
(2) Patterns where bilateral apparent AC thresholds do not differ significantly
(3) Summary

4.4 Criteria for masking

4.4-1 Criterion for masking through AC testing

(1) Cases in which bilateral apparent AC thresholds differ (e.g., AR0 < AL0)
(2) Cases in which bilateral apparent AC thresholds do not differ (AR0 = AL0)
(3) The audiogram defined by IaA values

4.4-2 Criteria for masking through BC testing

4.5 The true BC threshold which is the first cause of shadow hearing

4.6 Summary of Lecture 4

**** Further note ****

*) The main abbreviations are listed. AC: Air conduction, BC: Bone conduction,
SH: Shadow hearing, CH: Cross hearing, OM: Overmasking,
GR*: True air-bone (AB) gap of the right ear, GR0: Apparent AB gap of the right ear,
IaA: Interaural attenuation for AC signals, IaB: Interaural attenuation for BC signals,
AL-CH level [0]: CH level for AC in the left ear without masking.
AL-CH level [1]: CH level for AC in the left ear with N1.

4.1 Estimation of the true BC threshold range in the test ear

(1) An audiogram with SH thresholds

As shown in **Fig. 4-1**, the true AC threshold in the left ear (AL*) of 90 dB HTL at 1000 Hz has been obtained using the plateau method (**Fig. 4-2**). Thus, the apparent AC threshold in the left ear at that frequency (AL0 of 60 dB HTL) proves to be the SH threshold. As will be described later, the apparent BC threshold in the right ear (BR0) of 0 dB HTL is the true threshold (i.e., BR0 = BR*) (cf. **4.5**). At this time, the IaA value at 1000 Hz can be calculated as follows (cf. **1.2-3 [3]**, **2.1-3 [2]**):

1 kHz • IaA = AL0 − BR0 = AL0 − BR*
= 60 (dB HTL) − 0 (dB HTL)
= 60 dB.

After AC audiometry has been completed, that is, before masking for BC, what HTL in dB is the true BC threshold in the left ear (BL*)? Is the apparent BC threshold in the left ear (BL0) either the true or SH threshold?

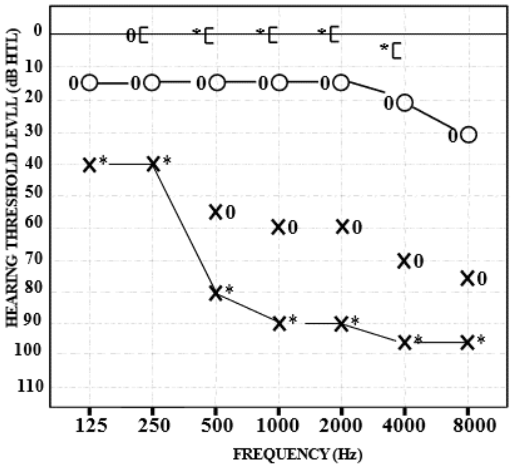


Figure 4-1 Audiogram with a shadow curve

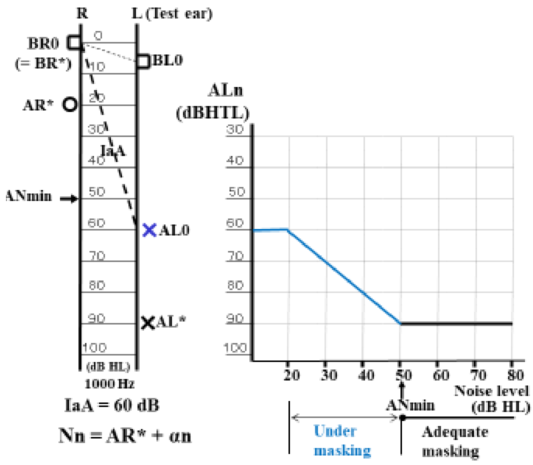


Figure 4-2 Plateau for AC at 1 kHz

(2) Cause and effect

The maximum limit of a conductive hearing loss is considered approximately 60 dB HTL because an AB gap is limited to IaA (**Fig. 4.3**), (cf. **1.4**). If a sensorineural disorder occurs in addition to the maximum conductive impairment such as congenital atresia of the external auditory canal, the true AC threshold is elevated above 60 dB HTL. As the true BC threshold in the left ear has been elevated, the true AC threshold in the same ear is also elevated (cf. **2.2-1**). Namely, the decline in BC hearing acuity is a cause and that in AC hearing acuity is an effect. Reversely, we are sometimes able to estimate the cause (i.e., the BC hearing loss) from the effect (i.e., the AC hearing loss).

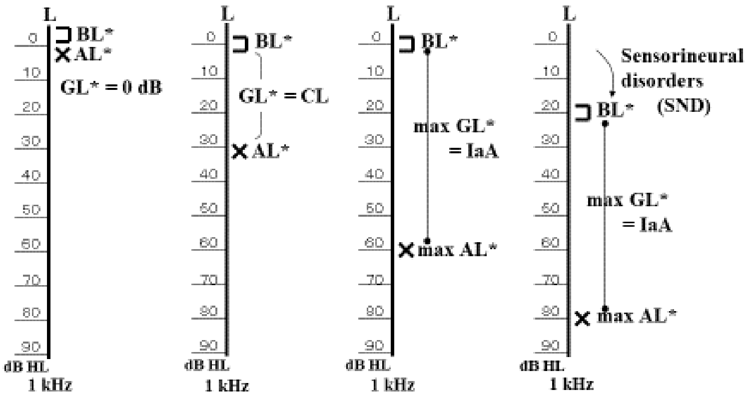


Figure 4-3 True BC and AC thresholds in the left ear

**** Further note ****

*) The apparent thresholds are measured without masking.

*) AC and BC are not quite different things but are indivisible from each other. This is the focal point of Lecture 4.

(3) The minimum level of the true BC threshold possible in the test ear

If the true AC threshold in one ear has been elevated above 60 dB HTL, its cause must be present. Some extent of sensorineural disorder is the cause and the effect is the true AC threshold elevation, as formulated below:

As shown in **Fig. 4-4**, when the left ear's true AC threshold (AL*) and IaA value at 1 kHz are determined to be 90 dB HTL and 60 dB, respectively, according to the relationship AB gap ≤ IaA, the minimum level of the true BC threshold possible in the left ear (min BL*) at 1 kHz is written as

$$\text{min BL}^* = \text{AL}^* - \text{IaA} = \text{AL}^* - (\text{AL0} - \text{BR0}) = 90\ (\text{dB HTL}) - 60\ (\text{dB})$$
$$= 30\ \text{dB HTL},$$

where BR0 is equal to the true threshold (BR0 = BR*), which is the cause of SH in the left ear (cf. **4.5**). In other words, if AL* is worse than 90 dB HTL, the true BC threshold in the left ear (BL*) must be worse than at least 30 dB HTL. Therefore, we can estimate the range within which the left ear's true BC threshold exists (i.e., BL* ≥ 30 dB HTL) before masking for BC.

From a different viewpoint, this may be written as follows (**Fig. 4-5**):

$$\text{min BL}^* = \text{AL}^* - \text{IaA} = \text{AL}^* - (\text{AL0} - \text{BR}^*) = \text{BR}^* + (\text{AL}^* - \text{AL0})$$
$$= \text{BR}^* + \omega = 0\ (\text{dB HTL}) + 30\ (\text{dB})$$
$$= 30\ \text{dB HTL},$$

where the amount of the AC threshold elevation in the left ear (ω = AL* − AL0) is 30 dB. In this formula, we need not calculate IaA values.

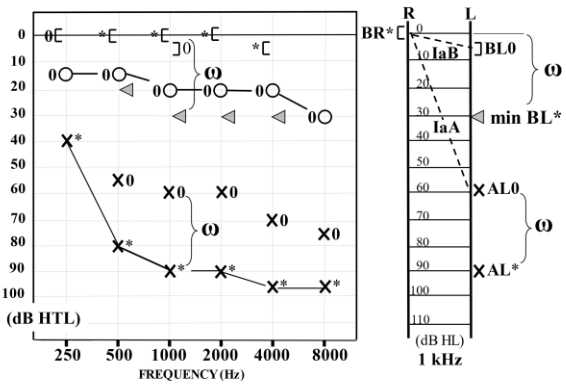


Figure 4-4 minBL* = AL* − IaA

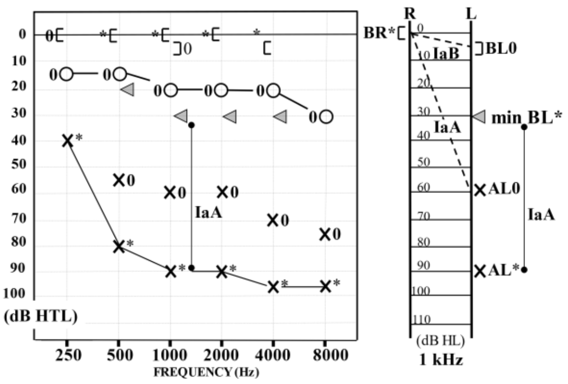


Figure 4-5 minBL* = BR* + ω

< An analogy of AC/BC thresholds and IaA >

Let us compare AL* to a fishhook and BL* to a float (**Fig. 4-6**). The length of the fish line between the fishhook and float is the AB gap. The maximum value of AB gaps is equal to the IaA value. If the rupture of the float (i.e., inner ear disorder) occurs, the float sinks (i.e., the true BC threshold is elevated), and the fishhook also sinks at the same time (i.e., the true AC threshold is also elevated). In reverse, if we can know the level of the fishhook (i.e., the AC threshold level), we may sometimes estimate the level of the float (i.e., the BC threshold level).

B : the float ・・・ the BC threshold
A : the fishhook ・・・ the AC threshold
A-B : the length of the fish line
・・・max AB gap = IaA
The rupture of the float
・・・the inner ear disorder
(or the retrocochlear damage)

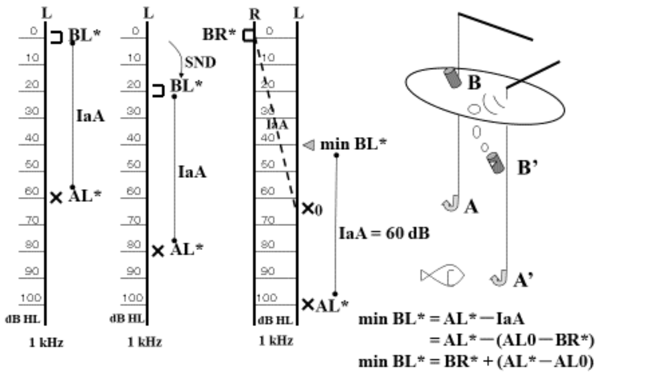


Figure 4-6 Link between the AC and BC thresholds

**** Further note ****

) According to the equation AB gap ≤ IaA (AL − BL* ≤ IaA), BL* ≥ AL* − IaA. ∴ minBL* = AL* − IaA.

*) In the operation of levels and quantities (amounts), each term of equality and inequality is represented as a numerical value (cf. **2.4 [1]**).

4.2 Requirements for apparent thresholds to be the SH thresholds

Let us consider the requirements for apparent AC and BC thresholds to be the SH thresholds. Conclusions derived from the discussions below are especially significant because we can clear away traditional expositions for clinical masking on the assumption of impossible audiometric configurations in actuality. For simplicity, the IaB value is supposed to be 0 dB.

According to the relationship AB gap ≤ IaA, the maximum level of the true AC threshold possible in the right ear (max AR*) and the left ear (max AL*) are determined as follows:

max AR* = BR* + IaA,
max AL* = BL* + IaA.

When the test signal is not heard by the test ear but is heard by the non-test ear, the threshold measured in the test ear is the SH threshold.

(1) Cases in which bilateral true BC thresholds are equal (i.e., BR* = BL*)

In **Fig. 4-7**, at 1 kHz, the apparent BC threshold in the left ear (BL0) of 0 dB HTL is clearly not the SH threshold. For AC, max AL* is written as follows:

max AL* = BL* + IaA
= 0 (dB HTL) + 60 (dB)
= 60 dB HTL.

The CH level for AC in the left ear corresponding to the true BC threshold in the right ear, BR* (AL-CH level [0]) is

AL-CH level [0] = BR* + IaA
= 0 (dB HTL) + 60 (dB)
= 60 dB HL (= max AL* ≥ AL*).

Since the true AC threshold in the left ear (AL*) is always lower than or equal to the AL-CH level [0]:

AL* ≤ AL CH level [0],

the apparent AC threshold in the left ear (AL0) cannot be the SH but always the true threshold.

The same observation holds for the right ear. Therefore, when BR* = BL*, all apparent AC and BC thresholds are not the SH thresholds.

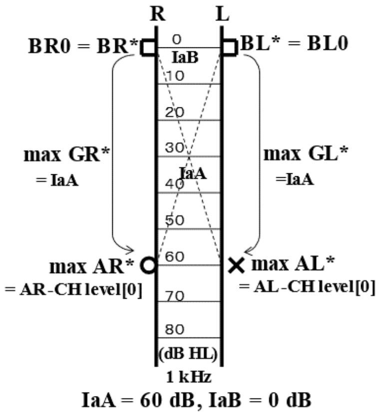


Figure 4-7 BR* = BL*

(2) Cases in which bilateral true BC thresholds differ (e.g., BR* < BL*)

As shown in **Fig. 4-8**, when BT0 of 0 dB HL (= BL-CH level [0]) is introduced into the left, poorer ear by BC, it is barely heard only by the right inner ear (BR*). Therefore, the apparent BC threshold in the left ear (BL0) of 0 dB HTL is always the SH threshold. For AC, when AL* is lower than or equal to the AL-CH level [0]:

AL* ≤ AL-CH level [0] = 60 dB HTL,

AL0 (≤ 60 dB HTL) cannot be the SH but always the true threshold (i.e., AL0 = AL*).

When AL* is higher than the AL-CH level [0]:

AL-CH level [0] < AL* ≤ maxAL*,
(i.e., 60 dB HTL < AL* ≤ 80 dB HTL),

and if AT0 of 60 dB HL (= AL-CH level [0]) is presented to the left ear, it is barely heard only by the right inner ear (BR*). Therefore, AL0 of 60 dB HTL is always the SH threshold.

By contrast, in the right, better ear by BC, both BR0 and AR0 are always the true thresholds (BR0 = BR*, AR0 = AR*) (cf. **6. 4-3 [5]**).

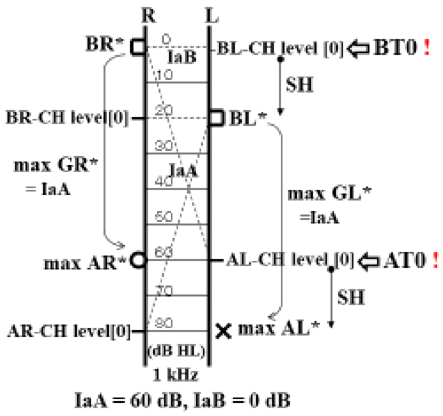


Figure 4-8 BR* < BL*

**** Further note ****

) According to the equation AB gap ≤ IaA, AL − BL* ≤ IaA and then, AL* ≤ BL* + IaA.
∴ maxAL* = BL* + IaA.

*) The measured thresholds are obtained by measuring with or without masking.

(3) Cases in which bilateral apparent AC thresholds differ (e.g., AR0 < AL0)

The apparent AC thresholds in the better ear by AC (AR0) in **Fig. 4-9** are always the true thresholds (AR0 = AR*) because AR* is always lower than the AR-CH level [0]. As shown in **Fig. 4-9 (b)**, the apparent AC threshold in the poorer ear by AC (AL0) can be the SH threshold only in the case where BR* < BL*. That is, when AL* is higher than the AL-CH level [0],

60 dB HTL (=AL-CH level [0]) < AL* ≤ 80 dB HTL (= maxAL*),

AL0 of 60 dB HTL is the SH threshold. At this time, BL0 of 0 dB HTL is also the SH threshold (cf. **Fig. 4-8**).

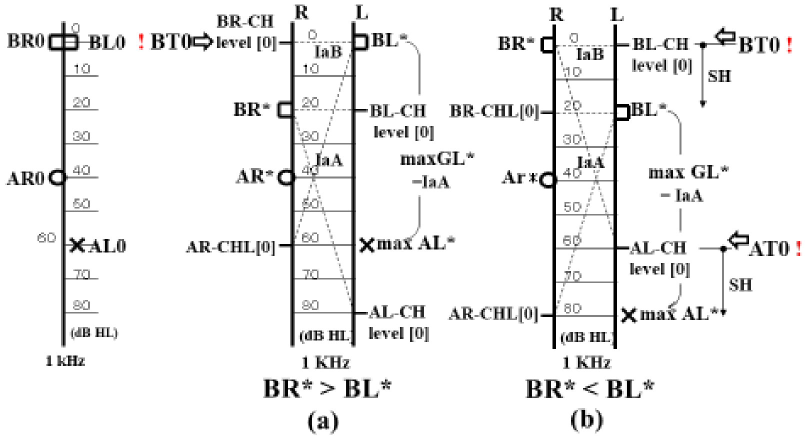


Figure 4-9 AR0 < AL0

In summary, at some frequency, when bilateral true BC thresholds are at the same level, all the apparent AC and BC thresholds are not the SH but always the true thresholds (cf. **Fig. 4-7**).

(4) The requirements for SH thresholds

It is assumed that the IaB value and measurement error are 0 dB.

1) The requirement for the apparent BC threshold to be the SH threshold is that bilateral true BC thresholds differ (i.e., a necessary and sufficient condition). The apparent BC threshold in the poorer ear by BC is always the SH threshold.
(The poorer ear by BC is the left in **Fig. 4-8**, the right ear in **Fig. 4-9 [a]**, and the left ear in **Fig. 4-9 [b]**.)

2) The requirements for the apparent AC threshold to be the SH threshold are that bilateral true BC thresholds differ (i.e., a necessary condition) and that the true AC threshold in the poorer ear by BC is higher than the CH level [0] for AC in the same ear (i.e., a sufficient condition). Then, the apparent AC threshold in the poorer ear by BC is always the SH threshold.
(The poorer ear by BC is the left ear in both **Fig. 4-8** and **Fig. 4-9 [b]**.)

3) Importantly, in a clinical situation, if the apparent AC threshold in one ear is the SH threshold, the apparent BC threshold in the same ear is always the SH threshold. That is, the side at which SH for AC and BC occurs is always the same.
(The same side is the left ear in both **Fig. 4-8** and **Fig. 4-9 [a]**.)

4) When the true BC thresholds differ, the apparent AC and BC thresholds in the better ear by BC are always the true thresholds.
(The better ear by BC is the right ear in **Fig. 4-8**, the left ear in **Fig. 4-9 [a]**, and the right ear in **Fig. 4-9 [b]**.)

5) When the apparent AC thresholds differ (e.g., AR0 < AL0), the apparent AC threshold in the better ear by AC (AR0) is always the true threshold (AR0 = AR*).
(The better ear by AC is the right in both **Fig. 4-9 [a]** and **[b]**.)

The true BC threshold in the better ear by BC in **Fig. 4-8**, **4-9** can cause SH of the test signals. The true BC threshold in the poorer ear by BC can never cause SH.

Although the requirements above seem to be a matter of course, it should be noted that they cannot be derived without the relationship AB gap ≤ IaA. From the discussion above, patterns of audiometric configurations at a given frequency can be classified.

**** Further note ****

*) Clinically, the difference between the apparent AC thresholds (≥15 dB) is assumed to be significant.

*) If IaB > 0 dB, the discussion above is too far complicated to be managed.

4.3 Patterns of audiometric configurations at a given frequency

According to the requirements for SH thresholds, audiometric configurations at a given frequency are classified into 12 patterns, as described below (**Fig. 4-10**, **4-11**). For simplicity, it is supposed that IaB = 0 dB and that the left ear is the poorer ear by AC. The difference between the apparent AC threshold in one ear (e.g., AL0) and the apparent BC threshold in the opposite ear (i.e., BR0) at some frequency is called air and opposite bone gap (AOB gap) (Gelfand, 2009):

Lt AOB gap = AL0 − BR0, **Rt AOB gap = AR0 − BL0**.

Here, the Lt and RT represent left and right, respectively. Moreover, the difference between bilateral apparent AC thresholds at some frequency is termed air and air gap (AA gap ≥ 0 dB):

Rt AA gap = AL0 − AR0 ≥ 0 dB, (AL0 ≥ AR0),

Lt AA gap = AR0 − AL0 ≥ 0 dB, (AR0 ≥ AL0).

In this lecture series, clinically significant AA gaps are larger than or equal to 15 dB (AA gap ≥ 15 dB) although theoretically, an AA gap of 5 dB is significant.

(1) Patterns where bilateral apparent AC thresholds differ significantly

Audiometric configurations are classified into seven patterns, as follows (**Fig. 4-10**):

Lt AOB gap = AL0 − BR0 = IaA (= 60 dB) and Rt AA gap = 20 dB.

[1]: all thresholds are not SH but true thresholds;
[2]: only BR0 is the SH threshold;
[3]: only BL0 is the SH threshold; or
[4]: both BL0 and AL0 are SH thresholds.

Lt AOB gap = AL0 − BR0 < IaA' (= 70 dB) and Rt AA gap = 20 dB.

[1']: all thresholds are not SH but true thresholds;
[2']: only BR0 is the SH threshold; or
[3']: only BL0 is the SH threshold.

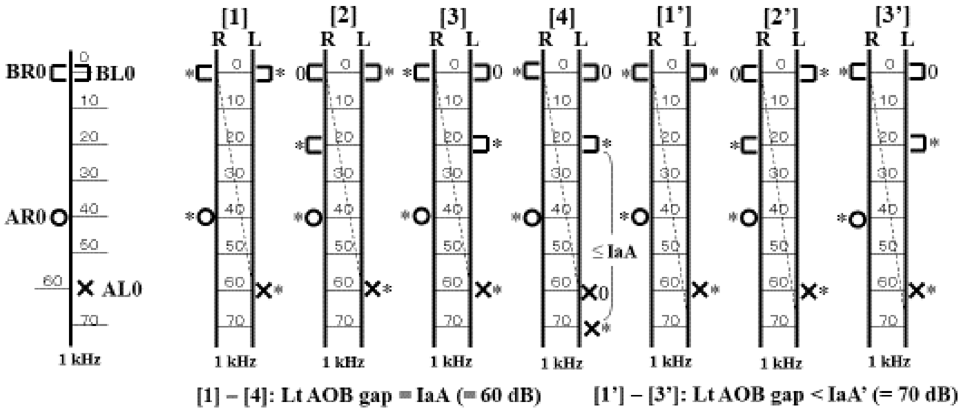


Figure 4-10 Audiometric patterns with Rt AA gap of 20 dB (AR0 < AL0)

Findings of these patterns above are as follows (cf. **Fig. 4-9**):

1) The apparent AC threshold in the better ear by AC (AR0) is always the true threshold.

2) The apparent AC threshold in the poorer ear by AC (AL0) is either the true or SH threshold. Only in pattern [4] can AL0 be the SH threshold, in which case the apparent BC threshold in the same ear (BL0) is also the SH threshold. Since BL0 < BL*, automatically BR0 = BR*. Furthermore, the IaA value can be calculated as follows:

IaA = Lt AOB gap = AL0 − BR0.

3) In all patterns except for pattern [4], we only know that IaA ≥ (AL0 − BL0) dB.

4) Evidently, the Lt AOB gap is never larger than IaA (Lt AOB gap ≤ IaA).

**** Further note ****

*) Note that the audiometric patterns at a given frequency are not the hearing patterns of the audiogram.

*) The AA gap is an important index to estimate the masking difficulty level (cf. Lecture 5, 6).

*) In the audiometric patterns shown in **Fig. 4-10**, the masking procedure for determining the true AC and BC thresholds in the poorer ear by AC is discussed in Lecture 5. The procedure for obtaining the true BC threshold in the better ear by AC is described in Lecture 6.

(2) Patterns where bilateral apparent AC thresholds do not differ significantly

Clinically, insignificant AA gaps are smaller than or equal to 10 dB (AA gap ≤ 10 dB). For simplicity, the cases with an AA gap of 0 dB (i.e., AR0 = AL0) are shown below.

Audiometric configurations are classified into five patterns as follows (**Fig. 4-11**):

Lt AOB gap = AL0 − BR0 = IaA (= 60 dB) and Rt AA gap = 0 dB.
- [5]: all thresholds are not SH but true thresholds;
- [6]: only BL0 is the SH threshold; or
- [7]: both BL0 and AL0 are SH thresholds.

Lt AOB gap = AL0 − BR0 < IaA' (= 70 dB) and Rt AA gap = 0 dB.
- [5']: all thresholds are not SH but true thresholds; or
- [6']: only BL0 is the SH threshold.

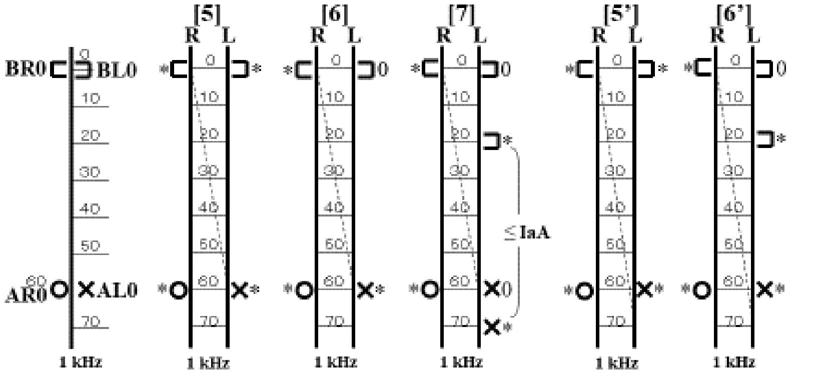


Figure 4-11 Audiometric patterns with an AA gap of 0 dB (AR0 = AL0)

Findings of these patterns above are as follows (cf. **Fig. 4-7**, **Fig. 4-8**):

1) The apparent AC and BC thresholds in at least one ear are the true thresholds.

2) Only in pattern [7] can the apparent AC threshold in one ear (e.g., AL0) be the SH threshold, in which case the apparent BC threshold in the same ear (i.e., BL0) is also the SH threshold (i.e., BL0 < BL*). Automatically, BR0 = BR* and the IaA value can be calculated (IaA = AL0 − BR0).

3) In all patterns except for pattern [7], we only know that IaA ≥ (AL0 − BR0) dB.

4) Evidently, bilateral AOB gaps are never larger than IaA (Rt or Lt AOB gap ≤ IaA).

Evidently, from **Fig. 4-10** and **Fig. 4-11**, the apparent AB gap (GR0 or GL0), which is the difference between the AC and BC thresholds measured in one ear without masking, is never larger than IaA.

(3) Summary

1) Only in patterns [4] and [7] can the apparent AC thresholds in one ear be the SH thresholds, in which cases the apparent BC thresholds in the same ear are also the SH thresholds.

2) The following gaps are never larger than IaA values.

True AB gaps: AL* − BL* = GL* ≤ IaA, or AR* − BR* = GR* ≤ IaA.
Apparent AB gaps: AL0 − BL0 = GL0 ≤ IaA, or AR0 − BR0 = GR0 ≤ IaA.
AOB gaps: AL0 − BR0 = Lt AOB gap ≤ IaA, or AR0 − BL0 = Rt AOB gap ≤ IaA.

3) Since the right and left are symmetric, the patterns are the same as the left-right reversal configurations. When AB gaps in these patterns are larger or smaller at variable proportions and/or the BC threshold levels are higher, the configurations fall under those in a clinical setting. Unilateral sensorineural and complete hearing impairments are included in patterns [4] or [7].

**** Further note ****

*) In patterns [6] and [6'] in **Fig. 4-11**, the poorer ear by BC may be either ear, because there is no significant difference between the true AC thresholds (cf. **Fig. 7-12**, **Fig. 7-16**).

*) Clinically, an AA gap of 5 dB is within the error range and is not significant (cf. **5.8 [1]**).

*) The masking procedure for the patterns in **Fig. 4-11** will be described in Lecture 6.

*) The apparent AB gap of one ear is significant to discuss the plateau widths (cf. **L. 7**) and occlusion effects (cf. **L. 10**).

4.4 Criteria for masking

The first step of the masking procedure is to determine whether masking is needed at every frequency, that is, whether the measured threshold can be the SH threshold or not.

4.4-1 Criterion for masking through AC testing

(1) Cases in which bilateral apparent AC thresholds differ (e.g., AR0 < AL0)

In **Fig. 4-12**, at frequencies except for 4 kHz, there are some differences between bilateral apparent AC thresholds (AA gaps > 0 dB). Then, according to the requirement for SH thresholds, the apparent AC thresholds in the better ear by AC (AR0) are all the true thresholds. In contrast, the apparent AC thresholds in the poorer ear by AC (AL0) are either the true or SH thresholds.

Here, assuming the minimum IaA values of 40 dB at all frequencies using supra-aural earphones, when the difference between AL0 and BR0 is larger than or equal to 40 dB, AL0 might be the SH threshold. Therefore, the criterion for masking through AC testing is as follows:

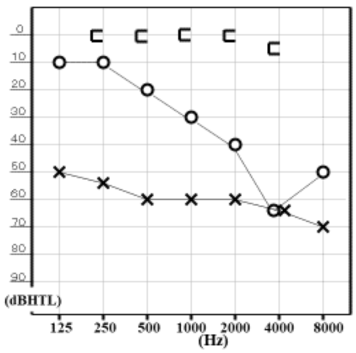
Lt AOB gap = AL0 − BR0 ≥ 40 dB = min IaA.

At 250, 500, 1000 and 2000 Hz in **Fig. 4-12**, the criterion is satisfied. Thus, AL0s might be the SH thresholds, which means the configurations at those frequencies might be pattern [4] (**Fig. 4-13**). As already described (cf. **2.1-3 [2]**), for example, the IaA value at 2000 Hz is larger than or equal to 60 dB without masking (**Fig. 4-12**, **4-13**):

IaA ≥ Lt AOB gap = AL0 − BR0 = 60 (dB HTL) − 0 (dB HTL) = 60 dB.

Note that the IaA value is never 40 or 50 dB (cf. **2.1-3 [1]**).

In principle, this criterion cannot be applied for the configurations at 125 Hz and 8 kHz in which BC thresholds are not measured. At 125 Hz, since the right ear's true BC threshold (BR*) is lower than or equal to 10 dB HTL (i.e., BR* ≤ AR0 = 10 dB HTL), the criterion is satisfied automatically. Thus, masking in the right ear is needed. However, at 8000 Hz, we have no way of knowing if AL0 of 70 dB HTL may be the SH threshold or not. This case will be discussed in Lecture 5 (cf. **5.6**).



125 Hz: Lt AOB gap ≥ AL0 − AR0 = 40 dB

Lt AOB gap = AL0 − BR0 ≥ 40 dB = min IaA.

250 Hz:
Lt AOB gap = 55 (dB HTL) − 0 (dB HTL) = 55 dB ≤ IaA.

500 Hz:
Lt AOB gap = 60 (dB HTL) − 0 (dB HTL) = 60 dB ≤ IaA.

1000 Hz:
Lt AOB gap = 60 (dB HTL) − 0 (dB HTL) = 60 dB ≤ IaA.

2000 Hz:
Lt AOB gap = 60 (dB HTL) − 0 (dB HTL) = 60 dB ≤ IaA.

Figure 4-12 Criterion for AC masking

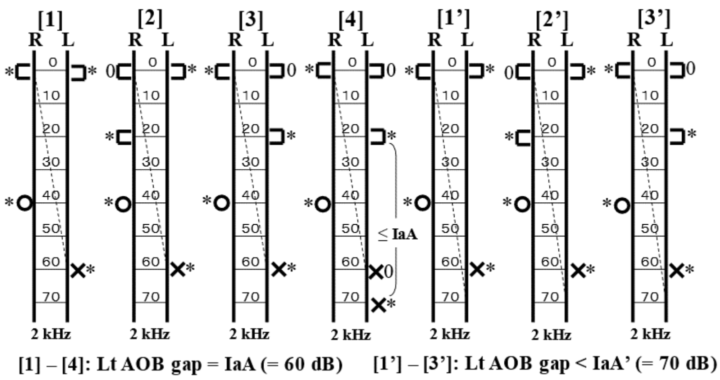


Figure 4-13 Audiometric patterns at 2000 Hz (Rt AA gap = 20 dB)

**** Further note ****

*) In **Fig. 4-12**, the hearing pattern of AC in the right ear might be estimated to a sensorineural impairment. The audiogram is for descriptive purposes in order to show the criterion in one figure.

*) At the frequencies where BC thresholds are not measured, how to perform masking for AC has not been described in the established commentary (cf. **5.6**).

(2) Cases in which bilateral apparent AC thresholds do not differ (AR0 = AL0)

In **Fig. 4-12** on the preceding page, there is no difference between bilateral apparent AC thresholds at 4000 Hz (AA gap = 0 dB). The criterion is applied as follows:

Lt AOB gap = AL0 − BR0 ≥ 40 dB, or
Rt AOB gap = AR0 − BL0 ≥ 40 dB.

The configuration at 4000 Hz is satisfied with the above criterion, and the apparent AC threshold in one ear might be the SH threshold (i.e., pattern [7]) (**Fig. 4-14**). This will be discussed in Lecture 6.

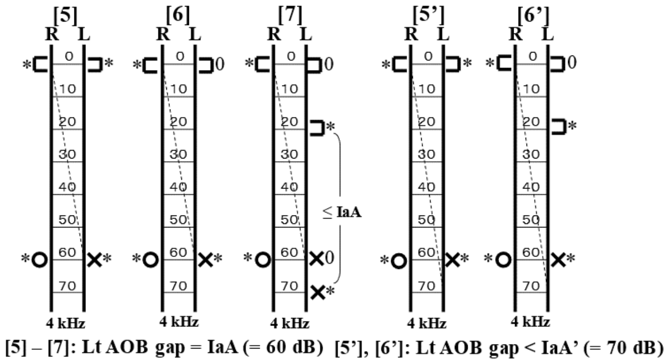


Figure 4-14 Audiometric patterns at 4000 Hz (AA gap = 0 dB)

According to **4. 4-1 (1)** and **(2)**, the criterion for masking through AC testing (the criterion for AC masking) is as follows:

Lt AOB gap = AL0 − BR0 ≥ 40 dB (= min IaA), or
Rt AOB gap = AR0 − BL0 ≥ 40 dB (= min IaA).

(3) The audiogram defined by IaA values

For the audiogram in **Fig. 4-12** on the preceding page, if the IaA values at all frequencies are 40 dB, the audiogram in **Fig. 4-15(a)** will be obtained. For instance, at 2000 Hz (**Fig. 4-15 [b]**), it is supposed that the right ear has normal BC acuity (BR* = 0 dB HTL) and the left ear is completely deaf. However severe conductive disturbance the right ear may have, the true AB gap of the right ear (GR*) is 40 dB (= IaA) and the apparent AB gap of the left ear (GL0) is also 40 dB (= IaA). Hence, both the true and apparent AB gaps are never larger than 40 dB of IaA (cf. **4.3 [3]**).

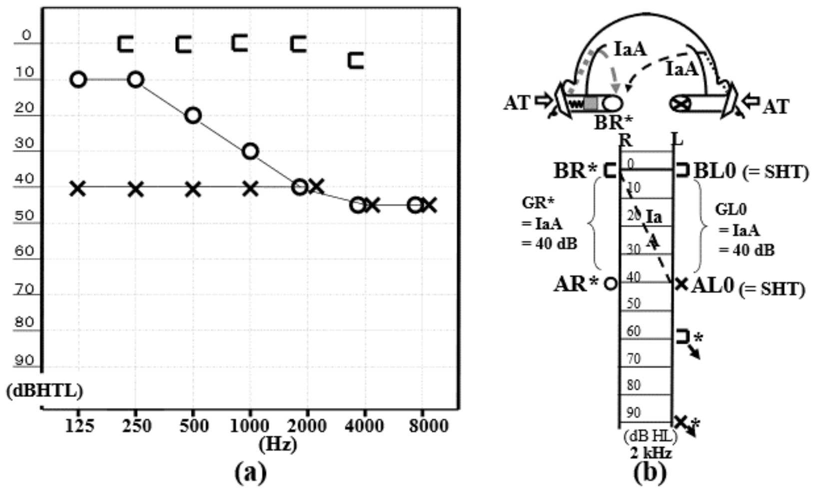


Figure 4-15 Audiogram with IaA values of 40 dB

**** Further note ****

*) **Fig. 4-15 (b)**, when the right ear has a profound conductive disorder (CL = 90 dB > IaA = 40 dB), the converted signal due to the AC test signal (40 dB HL) reaches the right cochlea via the direct-converted BC pathway. If this converted signal (0 dB HL) is barely heard by that cochlea, its hearing is considered true (AR* = 40 dB HTL). If we use the earphone with the IaA value of 80 dB, it would cause a serious problem that the true AC thresholds vary by the type of earphones (AR* = 80 dB HTL).

*) Assuming that the minimum IaA value is 50 dB clinically, the following criterion for AC masking may be a realistic approach: Lt AOB gap = AL0 − BR0 ≥ 50 dB.

4.4-2 Criteria for masking through BC testing

The IaB value with the BC vibrator placed at the mastoid is supposed to be 0 dB (IaB at mastoid = 0 dB). Theoretically, masking for BC is not needed only when both the true BC thresholds are equal and both AB gaps are 0 dB; i.e., bilateral normal hearing acuity or sensorineural impairment at the same level (**Fig. 4-16 [a]**). Therefore, except for such configurations, masking for BC is needed.

Clinically, as in **Fig. 4-16 (b)**, when the apparent AB gaps of the right and left ears are 5 dB and 10 dB, respectively, it might make no sense to attempt to obtain the true BC thresholds with masking in consideration of the measurement error of BC thresholds. In practice, masking for BC is needed when apparent AB gaps are ≥15dB (**Fig. 4-16 [c]**, **[d]**). Especially in **Fig. 4-16 (d)**, as bilateral AB gaps are ≥15 dB, masking for BC in both ears might be needed. The criteria for masking through BC testing-1 (the criteria for BC masking-1) are as follows:

Lt apparent AB gap = GL0 = AL0 − BL0 ≥ 15 dB, and, or
Rt apparent AB gap = GR0 = AR0 − BR0 ≥ 15 dB.

As shown in **Fig. 4-16 (e)**, if only the BC threshold is measured without masking in the better ear by AC, the criterion for BC masking is indicated as follows:

Lt AOB gap = AL0 − BR0 ≥ 15 dB.

At this time, since the apparent AB gap in at least one ear is ≥15 dB, BC masking is needed in at least one ear. **Table 4-1** shows the criteria for AC and BC masking.

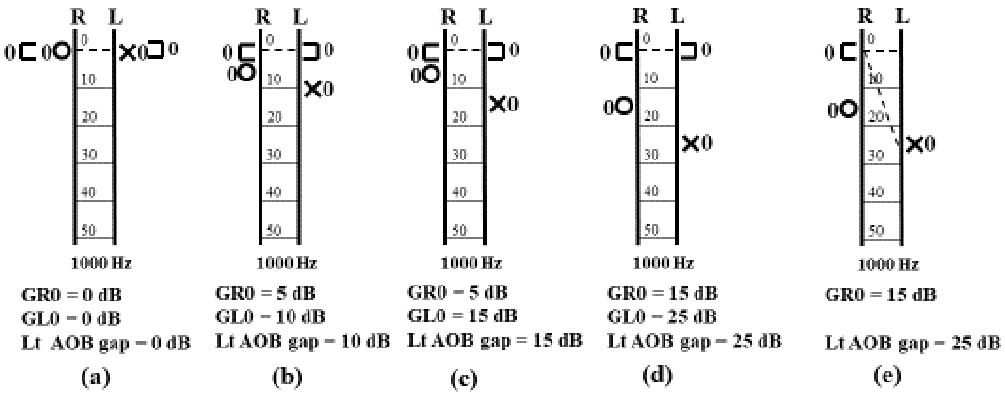


Figure 4-16 Apparent AB gaps and masking for BC

Table 4-1 Criteria for AC and BC masking

	AC masking	BC masking
1. 40 dB ≤ AOB gap	needed	needed
2. 15 dB ≤ AOB gap ≤ 35 dB	not needed	needed
3. 0 dB ≤ AOB gap ≤ 10 dB	not needed	not needed

As shown in **Fig. 4-16 (d)** and **(e)**, at the configurations in which both apparent AB gaps are larger than or equal to 15 dB (GR0 ≥ 15 dB, GL0 ≥ 15 dB), for example, if the left ear's true BC threshold (BL*) has been determined to be 25 dB HTL, evidently the right ear's apparent BC threshold (BR0) of 0 dB HTL is not the SH but true threshold. However, if BL* is 5 dB HTL (> BR0), BR0 of 0 dB HTL may be the SH threshold because of the measurement errors. Therefore, we need to mask the poorer ear by AC. This is the second criteria for BC masking, which will be discussed in Lecture 8 (cf. **8.4-4**).

**** Further note ****

*) Since IaB is assumed to be 0 dB, one of or both BR0 and BL0 is the true threshold.

4.5 The true BC threshold which is the first cause of shadow hearing

When the apparent AC thresholds in both ears differ significantly at frequencies except for 4000 Hz as shown in **Fig. 4-17**, we need to consider whether the AC thresholds in the poorer, left ear (AL0s) can be the SH thresholds or not. For example, the criterion for AC masking at 1000 Hz, is as follows:

Lt AOB gap = AL0 − BR0 = 60 (dB HTL) − 0 (dB HTL) = 60 dB > 40 dB.

Thus, AL0 of 60 dB HTL is possible to be the SH threshold. Therefore, the AC threshold in the left ear needs to be retested with masking in the right ear. Then, there are three combinations of the true BC thresholds in the configuration at 1000 Hz. **Fig. 4-17 (a)** shows that both apparent BC thresholds are the true thresholds. **Fig. 4-17 (b)**, **(c)** represents that one ear's apparent BC threshold is the true threshold and the other is the SH threshold. Understandably, both ears' apparent BC thresholds cannot be the SH thresholds at the same time.

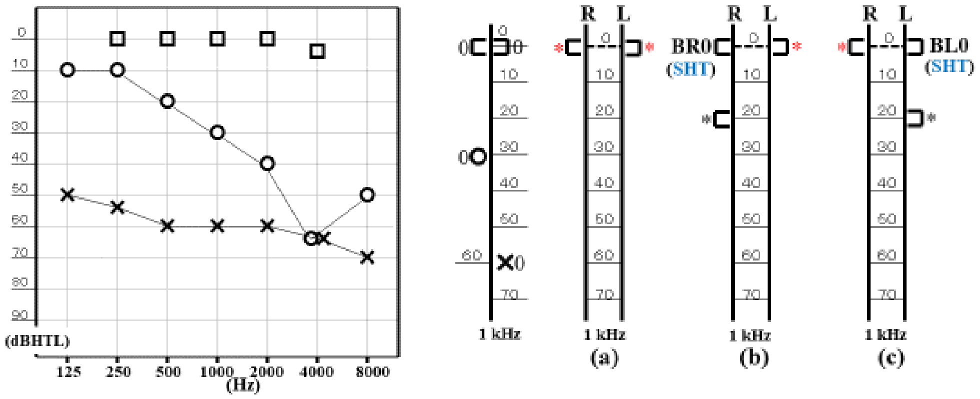


Figure 4-17 Audiogram without masking and three combinations of the BC thresholds

The case in which the apparent AC threshold in the left ear (AL0) is the SH threshold is exclusively limited to the pattern [4] (**Fig. 4-18**). Then, the apparent BC threshold in the right ear (BR0) is the true threshold (BR0 = BR*), and BR* is the first cause of SH. When BR0 is the SH threshold as in patterns [2] and [2'], both AL0 and BL0 are always the true thresholds (AL0 = AL*, BL0 = BL*). Namely, when we consider that AL0 might be the SH threshold, we will mask the right ear assuming that BR0 is the true threshold (i.e., the pattern [4]). However, even if BR0 is the true threshold, AL0 cannot be the SH threshold in patterns [1], [3], [1'], and [3']. Therefore, that BR0 is the true threshold is a necessary (not sufficient) condition for AL0 to be the SH threshold. The same holds true for BC.

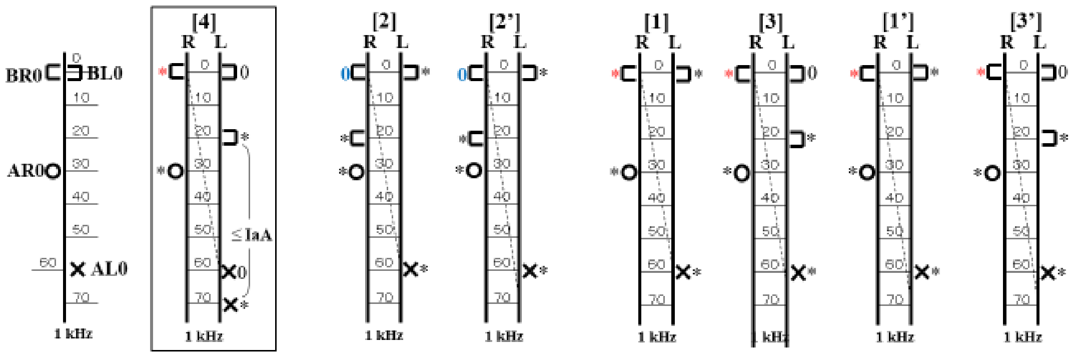


Figure 4-18 Right ear's true BC threshold: the first cause for shadow hearing

To consider that AL0 might be the SH threshold is to assume that its audiometric configuration might be the pattern [4].

If AL0 is the SH threshold (AL0 < AL*),

1) BR0 is the true threshold (BR0 = BR*): the first cause of SH.
2) BL0 is also the SH threshold (BL0 < BL*): AB gap ≤ IaA.
3) IaA = Lt AOB gap = (AL0 – BR0) dB.

4.6 Summary of Lecture 4

1. At some frequency, if the apparent AC threshold in the left ear (AL0) is proved to be the SH threshold and the true AC threshold in the left ear (AL*) is determined, then, the minimum level of the true BC threshold possible in left (test) ear (min BL*) is represented as follows:

min BL* = AL* − IaA, or

min BL* = BR* + ω,

where IaA = AL0 − BR*, BR0 = BR*, and ω = AL* − AL0.

We can estimate the range within which the true BC threshold in the left ear exists before masking for BC. Note that the true BC threshold in the right ear (BR*) is the first cause of SH of the test signal.

2. The requirements for the apparent thresholds (the thresholds measured without masking) to be the SH thresholds are as follows:

1) The requirement for apparent BC thresholds to be the SH thresholds is that bilateral true BC thresholds differ (i.e., a necessary and sufficient condition). The apparent BC threshold in the poorer ear by BC is always the SH threshold.

2) The requirement for apparent AC thresholds to be the SH thresholds is that bilateral true BC thresholds differ (i.e., a necessary condition) and that the true AC threshold in the poorer ear by BC is higher than the CH level [0] for AC in the same ear (i.e., a sufficient condition). The apparent AC threshold in the poorer ear by BC is always the SH threshold.

3) Importantly, in a clinical situation, if the apparent AC threshold in one ear is the SH threshold, the apparent BC threshold in the same ear is always the SH threshold. That is, the side at which SH for AC and BC occurs is always the same side.

4) When the true BC thresholds differ, the apparent AC and BC thresholds in the better ear by BC are always the true thresholds.

5) When the apparent AC thresholds differ (AR0 < AL0), the apparent AC threshold in the better ear by AC (AR0) is always the true threshold (AR0 = AR*).

3. Audiometric configurations at some frequency are classified into 12 patterns. Only in patterns [4] and [7] can the apparent AC thresholds in one ear be the SH thresholds, in which cases the apparent BC thresholds in the same ear are also the SH thresholds. The IaA value can be calculated (IaA = AL0 − BR0).

4. It should be noted that all sorts of gaps below are never larger than IaA values.

Lt true AB gap = AL* − BL* = GL* ≤ IaA,

Lt apparent AB gap = AL0 − BL0 = GL0 ≤ IaA,

Lt AOB gap = AL0 − BR0 ≤ IaA.

The difference between bilateral apparent AC thresholds at some frequency is termed an air and air gap (AA gap ≥ 0 dB):

Rt AA gap = AL0 − AR0 ≥ 0 dB, (AL0 ≥ AR0),

Lt AA gap = AR0 − AL0 ≥ 0 dB, (AR0 ≥ AL0).

5. Criteria for masking through AC and BC testing

a) Criterion for AC masking: when the AOB gap in at least one ear is larger than or equal to 40 dB, the apparent AC threshold in at least one ear might be the SH threshold.

b) Criteria for BC masking: when the apparent AB gap or AOB gap in at least one ear is larger than or equal to 15 dB, the BC threshold in the same ear might be the SH threshold.

Masking is needed in the opposite ear.

6. To consider that AL0 might be the SH threshold is to assume that its audiometric configuration might be the patterns [4] or [7].

If AL0 is the SH threshold (AL0 < AL*),

1) BR0 is the true threshold (BR0 = BR*): the first cause of SH.

2) BL0 is the SH threshold (BL0 < BL*): AB gap ≤ IaA.

3) IaA = Lt AOB gap = (AL0 − BR*) dB.

Lecture 5 Theoretical masking procedure

In this lecture, we demonstrate the most efficient masking method without overmasking. It is a theoretical model to understand the fundamental structure of masking. The clinical application of the present method is discussed in Lecture 8.

5.1 Basic audiograms

(1) Significant AA and AOB gaps
(2) Audiometric configurations at some frequency

5.2 The maximum level of masking noise that has no possibility of overmasking

5.3 Masking for Air Conduction Audiometry

5.3-1 Masking procedure for AC in pattern [4]

(1) N1 = 60 dB HL (= AL0), $\alpha 1$ = N1 − AR* = 15 dB.
(2) N2 = 75 dB HL (= AL1), $\alpha 2$ = N2 − AR* = 30 dB.
(3) N3 = 80 dB HL (= AL2 = AL*), $\alpha 3$ = N3 − AR* = 35 dB.

5.3-2 The AC plateau in pattern [4]

5.3-3 Masking procedure for AC of the present method

5.4 Masking for Bone Conduction Audiometry

5.4-1 Masking procedure for BC in pattern [4]

(1) N1 = 80 dB HL (= AL*), $\alpha 1$ = N1 − AR* = 35 dB.
(2) N2 = 95 dB HL (= N1 + $\theta 1$), $\alpha 2$ = N2 − AR* = 50 dB.
(3) N3 = 100 dB HL (= N2 + $\theta 2$), $\alpha 3$ = N3 − AR* = 55 dB.

5.4-2 The BC plateau in pattern [4]

5.4-3 Masking procedure for BC of the present method

5.5 Masking procedure in patterns except for pattern [4]

(1) Pattern [3] at 1000 Hz
(2) Pattern [3’] at 250 Hz

5.6 Masking for AC at 125, 8000 Hz

5.7 The true AB gap of the non-test ear and a singular level

5.8 Significant AA gaps

(1) The application of the present method
(2) Patterns in which masking for BC in the poorer ear by AC is needed

5.9 Points of attention

(1) Tow challenges of the noises for the present method
(2) Central making
(3) Occlusion effects
(4) Subdivided patterns of patterns [4] and [7]

5.10 Summary of Lecture 5

**** Further note ****

*) The main abbreviations are listed. AC: Air conduction, BC: Bone conduction,
SH: Shadow hearing, CH: Cross hearing, OM: Overmasking,
GR*: True air-bone (AB) gap in the right ear, GR0: Apparent AB gap in the right ear,
IaA: Interaural attenuation for AC signals, IaB: Interaural attenuation for BC signals,
AL-CH level [0]: CH level for AC in the left ear without masking.
AL-CH level [1]: CH level for AC in the left ear with N1.

5.1 Basic audiograms

(1) Significant AA and AOB gaps

An AA gap is a difference between the apparent AC thresholds in both ears at a given frequency (cf. **4.3** **[3]**). In this lecture series, significant AA gaps are assumed to be more than or equal to 15 dB (cf. **5-8**). For simplicity, it is assumed that the right ear is the better ear by AC and the left ear is the poorer ear by AC (AR0 < AL0). **Fig. 5-3** on the next page shows the basic audiograms in which audiometric configurations are broken down into patterns based on AA and AOB gaps. The AC and BC thresholds are all measured without masking.

a) The AA gaps in **[A-0]** and **[B-0]** are significant (Rt AA gap = AL0 − AR0 ≥ 15 dB). The AA gaps in **[C-0]** are not significant (Rt AA gap ≤ 10 dB).

b) **[A-1]**, **[B-1]**, and **[C-1]** are added to the apparent BC thresholds in the right ear (BR0s).

For AC, in **[A-1]** and **[B-1]**, since Lt AOB gap ≥ 40 dB, the AC thresholds in the poorer ear (AL0s) may be the SH thresholds. Thus, masking for the left AC is needed (cf. **2.4** **[4]**). In **[C-1]**, since bilateral AOB gaps are ≥ 40 dB, the AC threshold measured in one ear can be the SH threshold. Therefore, masking for AC in at least one ear is needed.

For BC, in **[A-1]**, **[B-1]**, and **[C-1]**, since Lt AOB gap ≥ 15 dB, masking for the left BC is needed. Furthermore, in **[B-1]** and **[C-1]**, masking for the right BC is needed at sometimes.

c) In **[B-2]** and **[C-2]**, since 15 dB ≤ Lt AOB gap < 40 dB, only masking for BC is needed.

d) In **[C-3]**, since Lt AOB gap ≤ 15 dB, masking for both AC and BC is not needed.

Each basic audiogram corresponds to the audiometric configuration patterns in **Fig. 5-1** and **5-2**.

(2) Audiometric configurations at some frequency

Note that only in patterns [4] and [7] can the apparent AC threshold in the left, poorer ear (AL0) be the SH threshold (cf. **Fig. 5-1**, **5-2**). If AL0 is the SH threshold (AL0 < AL*),

1) BR0 is the true threshold (BR0 = BR*): the first cause of SH,
2) BL0 is the SH threshold (BL0 < BL*): AB gap ≤ IaA, and
3) IaA = Lt AOB gap = (AL0 − BR*) dB.

In the other patterns, AL0s are the true thresholds (AL0 = AL*), and IaA ≥ Lt AOB gap.

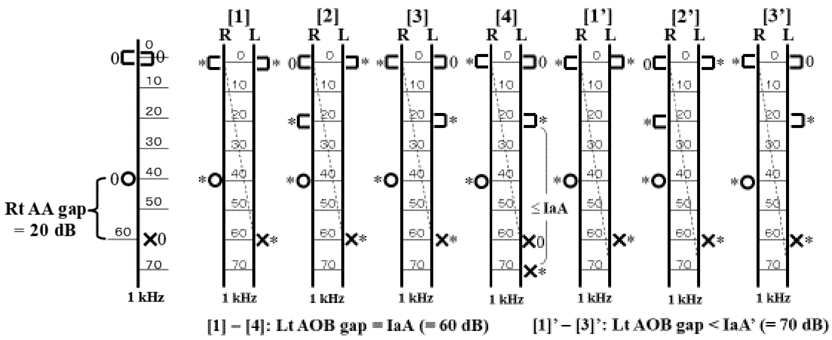


Figure 5-1 Audiometric configuration patterns (Rt AA gap ≥ 15 dB)

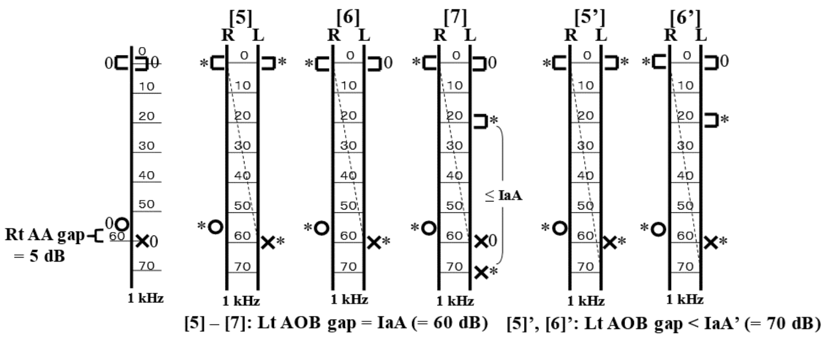
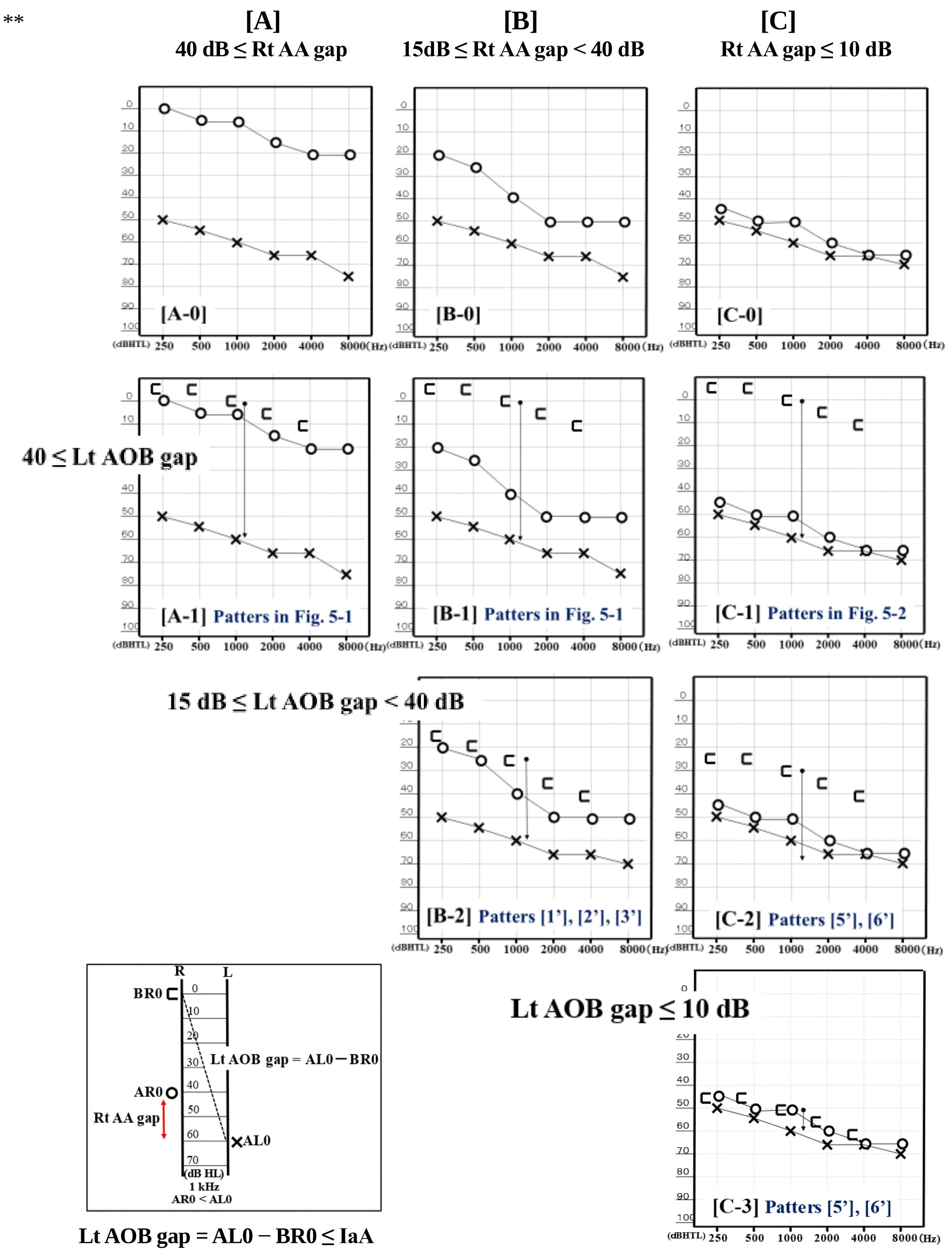


Figure 5-2 Audiometric configuration patterns (Rt AA gap ≤ 10 dB)

**** Further note ****

*) The apparent AC threshold is measured without masking.

*) "Masking for the left AC is needed" means that the masking noise needs to be presented to the right ear to obtain the true AC threshold of the left ear.



Lt AOB gap = AL0 − BR0 ≤ IaA
Rt AA gap = AL0 − AR0, (AL0 ≥ AR0)

Figure 5-3 Basic audiograms

Table 5-1 Basic audiograms and criteria for masking AC and BC

	Basic audiograms	AC masking	BC masking
1. 40 dB ≤ Lt AOB gap	[A-1], [B-1], [C-1]	Needed	Needed
2. 15 dB ≤ Lt AOB gap < 40 dB	[B-2], [C-2]	Not needed	Needed
3. Lt AOB gap ≤ 10 dB	[C-3]	Not needed	Not needed

5.2 The maximum level of masking noise that has no possibility of overmasking

Fig. 5-4 shows an audiogram without masking, in which apparent AC thresholds differ significantly at frequencies except for 4 kHz. For example, in the audiometric configuration at 2000 Hz, the apparent AC threshold in the right, better ear (AR0) of 45 dB HTL is a true threshold. In contrast, according to the criterion for AC masking (cf. **4.4-1**),

Lt AOB gap = AL0 − BR0
= 60 (dB HTL) − 0 (dB HTL)
= 60 dB > 40 dB = min IaA.

Then, the apparent AC threshold in the left, poorer ear (AL0) of 60 dB HTL is possibly the SH threshold. Therefore, let us mask the right ear and retest the AC threshold in the left ear.

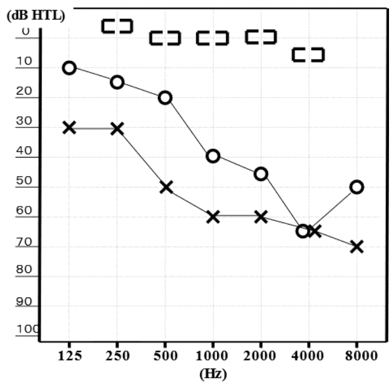


Figure 5-4 Audiogram without masking

When the initial masking noise (N1) of the level equal to AL0 (N1 = 60 dB HL) is presented to the right (non-test) ear, in all patterns the OM level [1] does not exceed the true BC threshold level in the test ear (BL*), as follows (**Fig. 5-5**):

Pattern [1], [2]: OM level [1] = N1 − IaA = BL0 = BL*,
Pattern [3], [4]: OM level [1] = N1 − IaA = BL0 < BL*,
Pattern [1'] - [3']: OM level [1] = N1 − IaA' < BL0 ≤ BL*.

Therefore, OM never occurs in any pattern. However, if the masking noise levels are higher than the level of N1, then OM always occurs in patterns [1] and [2]. Given only the information that the true BC threshold in the left (test) ear is higher than or equal to BL0 (BL* ≥ BL0 = 0 dB HTL), N1 (= AL0) is the maximum level of masking noise that has no possibility of OM (**MNnpo**).

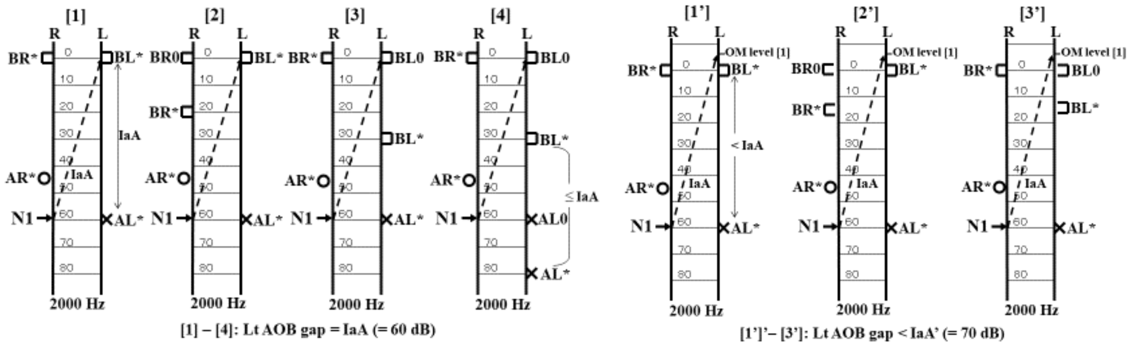


Figure 5-5 MNnpo

With the masking noise of N1 in the right (non-test) ear, since N1 never causes OM, we should only consider whether the AC threshold measured in the test ear with N1 (AL1) is the true or SH threshold. Before masking, we should provide more insight, as follows:

a) When AL1 is not elevated above AL0 (AL1 = AL0), we know that the configuration is one of the patterns except for pattern [4], and that AL0 is determined to be the true threshold. We only know that IaA ≥ 60 dB (IaA ≥ AL0 − BR0 = 60 dB).

b) When AL1 is elevated above AL0 (AL1 > AL0), the configuration is only the case of the pattern [4], and AL0 proves to be the SH threshold. Furthermore, the following facts are established (cf. **4.5**):
1) BR0 is the true threshold (BR0 = BR*): the first cause of SH.
2) BL0 is also the SH threshold (BL0 < BL*): AB gap ≤ IaA.
3) IaA can be calculated (IaA = AL0 − BR0 = 60 dB).

Next, a masking method by using MNnpo is described.

**** Further note ****

*) OM level [n] = (Nn − IaA) dB HL (cf. **2.3-1**).

*) MNnpo is not always equal to the maximum level of masking noise that OM does not occur (MN). MN cannot be determined until the true BC threshold in the test ear and IaA have been obtained.

*) In **Fig. 5-6** on the next page, AT0 is the AC test signal that the participant barely hears without masking, likewise for BT0 as regards the BC test signal. In **Fig. 5-7** on the next page, AT1 is the AC test signal that the participant barely hears when masking with N1.

5.3 Masking for Air Conduction Audiometry

5.3-1 Masking procedure for AC in pattern [4]

The masking procedure of the present method is discussed in the following audiometric configuration at 2000 Hz with pattern [4] in **Fig. 5-4** on the preceding page.

	The right (non-test) ear	The left (test) ear	Interaural attenuation
Bone conduction	BR* = 0 dB HTL	BL* = 40 dB HTL	IaB = 0 dB
Air conduction	AR* = 45 dB HTL	AL* = 80 dB HTL	IaA = 60 dB

The measured thresholds shown in **Fig. 5-6** are obtained without masking. The apparent AC and BC thresholds in the left (test) ear (AL0 = 60 dB HTL, BL0 = 0 dB HTL) are both the SH thresholds (cf. **3.1-1**). The examiner will consider that AL0 might be the SH threshold, and mask the right ear. The procedures are as follows:

a) Consider whether the n-th masking noise (Nn; n = 1, 2, 3, …) causes OM or not.

b) Identify the level of the AC test signal (AT) that is barely heard by the participant, and obtain the AC threshold measured in the test ear with Nn (ALn).

c) Determine whether the measured AC threshold is the true or false (SH or OM) threshold.

d) Estimate the range of the true BC threshold possible in the test ear.

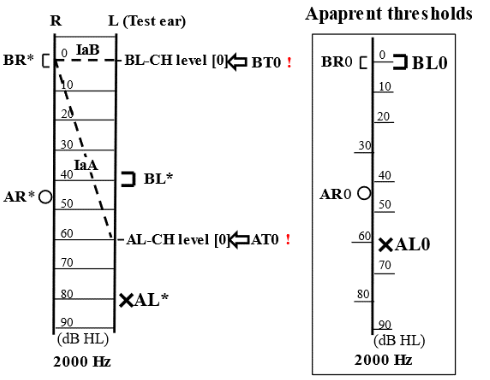


Figure 5-6 Thresholds without masking

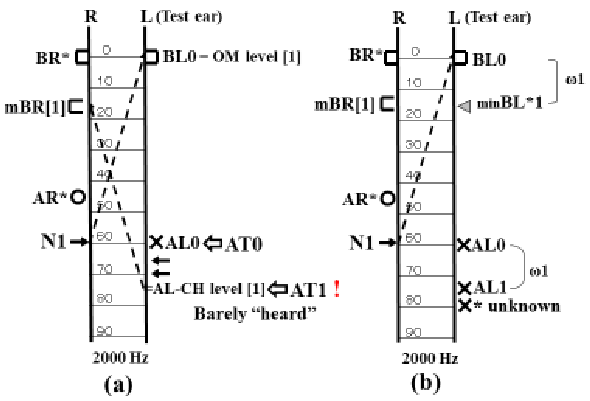


Figure 5-7 N1 = 60 dB HL (= AL0)

(1) N1 = 60 dB HL (= AL0), α1 = N1 − AR* = 15 dB.

N1 of the level equal to AL0 (N1 = [AL0] dB HL, cf. **2.4 [1]**) is presented to the right ear.

a) As previously mentioned, OM does not occur (**Fig. 5-7 [a]**). At this time, the examiner is unaware of the value of IaA. If he or she assumes this configuration to pattern [4], IaA can be calculated as 60 dB (= AL0 − BR0) (cf. **4-5**). The CH level for AC in the left ear with N1 (AL-CH level [1]) predicted by the examiner is as follows:

AL-CH level [1] = mBR[1] + IaA = (BR* + α1) + IaA = 15 (dB HTL) + 60 (dB)
= 75 dB HL,

where mBR[1] is the right ear's BC threshold masked by N1. The examiner will predict that the AC threshold measured in the test ear with N1 (AL1) is in the 60 to 75 dB HTL range (cf. **7-6**).

b) As the level of AT is raised from 60 dB HL (= AT0) in 5-dB steps, the participant will barely hear the initial AC test signal (AT1) of 75 dB HL (**Fig. 5-7 [a]**). Then, the examiner obtains AL1 of 75 dB HTL, which is higher than AL0 (AL1 > AL0). Therefore, he/she knows that the configuration is a pattern [4], that is, AL0 of 60 dB HTL is the SH threshold, BL0 of 0 dB HTL is also the SH threshold, BR0 = BR*, and IaA = 60 dB. The AL-CH level [1] is determined to be 75 dB HTL.

c) The examiner cannot be sure whether AL1 of 75 dB HTL is the true or SH threshold. This is because, whenever the true AC threshold in the test ear is higher than or equal to 75 dB HTL (AL* ≥ 75 dB HTL), the participant will always barely hear AT1 of 75 dB HL that is equal to the AL-CH level [1].

d) Since the amount of the AC threshold elevation in the test ear with N1 (ω1) is 15 dB (ω1 = AL1 − AL0 = 15 dB), the minimum level of the true BC threshold possible in the left (test) ear with N1 (min BL*1) is as follows (cf. **4.1 [3]**):

min BL*1 = BR0 + ω1 = 0 (dB HTL) + 15 (dB)
= 15 dB HTL.

The examiner realizes that BL* is ≥ 15 dB HTL at this stage (**Fig. 5-7 [b]**).

(2) N2 = 75 dB HL (= AL1), $\alpha2$ = N2 − AR* = 30 dB.

The second masking noise (N2) of the level equal to the AC threshold level measured in the test ear with N1 (AL1) (N2 = [AL1] dB HL) is presented to the non-test ear (**Fig. 5-8 [a]**).

a) OM level [2] = N2 − IaA = 75 (dB HL) − 60 (dB)
= 15 dB HL (= min BL*1 $\leq$ BL*).
Thus, N2 does not cause OM and is also MNnpo.

b) AL-CH level [2] = mBR[2] + IaA = 30 (dB HTL) + 60 (dB)
= 90 dB HL (> AL* = 80 dB HTL).
As the level of AT is raised from 75 dB HL (= AT1) in 5-dB steps, the participant will barely hear the second BC test signal (AT2) of 80 dB HL (**Fig. 5-8 [b]**). Then, the examiner obtains the AC threshold measured in the test ear with N2 (AL2) of 80 dB HTL (**Fig. 5-8 [c]**).

c) Since AT2 of 80 dB HL is lower than the predicted AL-CH level [2] of 90 dB HL, the examiner knows that AT2 is not heard by the non-test inner ear (mBR[2]), that is, the hearing of AT2 is not SH. AT2 is barely heard by the test inner ear (BL*). Therefore, he/she will consider AL2 of 80 dB HTL as the true threshold (AL2 = AL*). At this time, at least theoretically, the true AC threshold in the test ear has been determined.

d) Since the amount of the AC threshold elevation in the test ear with N2 ($\omega2$) is 5 dB ($\omega2$ = AL2 − AL1 = 5 dB), the minimum level of the true BC threshold possible in the test ear with N2 (minBL*2) is as follows (**Fig. 5-8 [c]**):
min BL*2 = minBL*1 + $\omega2$ = 15 (dB HTL) + 5 (dB)
= 20 dB HTL.

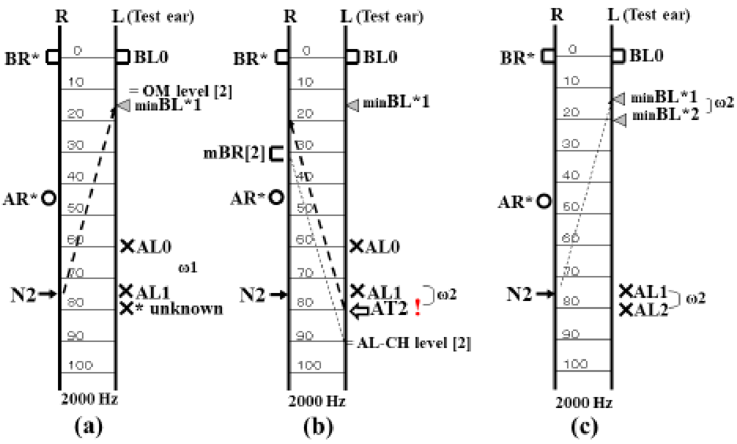


Figure 5-8 N2 = 75 dB HL (= AL1)

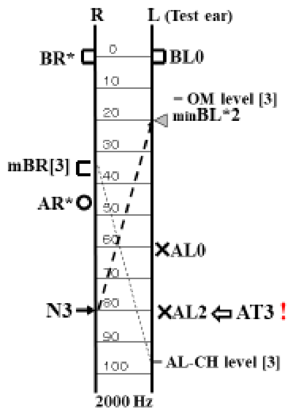


Figure 5-9 N3 = 80 dB HL

(3) N3 = 80 dB HL (= AL2 = AL*), $\alpha3$ = N2 − AR* = 35 dB.

Set the third masking noise (N3) to a level equal to AL2 or the true threshold level (**Fig. 5-9**).

a) OM level [3] = N3 − IaA = 80 (dB HL) − 60 (dB)
= 20 dB HL (= min BL*2 $\leq$ BL*).
N3 does not cause OM and is also MNnpo.

b) AL-CH level [3] = mBR[3] + IaA = 35 (dB HTL) + 60 (dB)
= 95 dB HL (> AL*).
The participant will barely hear the third AC test signal (AT3) of 80 dB HL (= AT2). Then, the examiner obtains the AC threshold measured in the test ear with N3 (AL3) of 80 dB HTL, which is not higher than AL2 (AL3 = AL2).

c) The lack of threshold elevation indicates that SH has not occurred. The examiner can be sure that AL3 is the true threshold. The clinical meaning of this final step is discussed in Lecture 8.

**** Further note ****

*) In **Fig. 5-8**, AT2 is the AC test signal that the participant barely hears when masking with N2.

*) There are three characters in this simulated audiometry. The first is the participant who will respond to the test signal as hearing or not hearing only. The second is the examiner who does not know the true threshold and will attempt to determine whether the measured thresholds are true or false, relying only on the response of the participant. The third is you who know everything and observe their interaction.

5.3-2 The AC plateau in pattern [4]

The present method using MNnpo is more efficient than the plateau method (**Fig. 5-10**) because the true thresholds are identified in fewer steps with N1, N2, and N3.

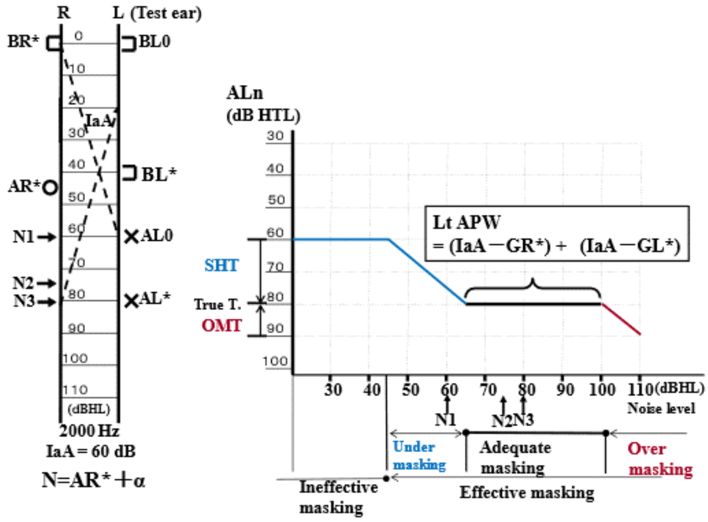


Figure 5-10 MNnpo and AC plateau

5.3-3 Masking procedure for AC of the present method

The above example can be generalized with the following procedure (**Fig. 5-11**). When bilateral apparent AC thresholds differ significantly (e.g., AR0 < AL0, Rt AA gap = AL0 − AR0 ≥ 15 dB) and the difference between AL0 and BR0 is greater than or equal to 40 dB (Lt AOB gap = AL0 − BR0 ≥ 40 dB), then the test ear is the left, poorer ear by AC and the non-test ear is the right, better ear by AC.

The n-th masking noise (Nn) of the level that is equal to the AC threshold level measured in the left (test) ear with Nn-1 (ALn-1) is presented to the right (non-test) ear:

Nn = [ALn-1] dB HL, (n = 1, 2, 3, …),

where AL0 is the AC threshold measured in the test ear without masking. If the AC threshold measured in the test ear with Nn (ALn) is not higher than ALn-1 (ALn = ALn-1), ALn is the true threshold. If the measured AC thresholds continue to be elevated and the participant does not respond to the AC test signal at the limits of the audiometer, then a complete loss of hearing is evidenced. The present masking procedure using the maximum level of masking noise that has no possibility of OM (MNnpo) is theoretically the most efficient option (cf. **7.6 [5]**). This basic idea was first described in Isogai's ABCI method (Isogai, 1986).

In the above example, to clarify that OM does not occur, the range of the true BC threshold possible in the test ear has been estimated, and the IaA value has been calculated. However, only the AC thresholds measured in the test ear are necessary to set the masking noise levels for this procedure. Therefore, the present method can be applied to frequencies at which BC thresholds are not measured, such as 125 Hz and 8000 Hz. When testing, the IaA values need not be calculated.

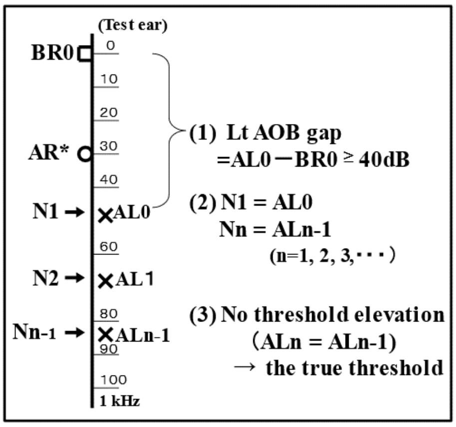


Figure 5-11 Masking procedure for AC

**** Further note ****

*) The example above is cramped with an AA gap of only 15 dB for the purpose of demonstrating the masking procedure for AC and BC in one case and in three noise steps. If the AA gap is larger, the thresholds are easy to obtain.

*) In lecture 4 (**4.4-1 [1]**), the initial masking noise level at 8000 Hz in **Fig. 4-12** may be set to 70 dB HL.

5.4 Masking for Bone Conduction audiometry

5.4-1 Masking procedure for BC in pattern [4]

As shown in **Fig. 5-12(a)**, since the difference between AL* and AL0 at 2000 Hz is 20 dB (ω = AL* − AL0 = 20 dB), the true BC threshold in the test ear is ≥ 20 dB HTL (BL* ≥ BL0 + ω = 20 dB HTL, BL0 = BR*, IaB = 0 dB; cf. **4-1 [3]**). At the point masking for AC has been completed, the minimum level of the true BC threshold possible in the left (test) ear is defined as a standard level of the BC threshold in the left ear (BLs): BLs = BL0 + (AL* − AL0) = BL0 + ω = 20 dB HTL.

The basic procedure is the same as the one for AC.

a) Consider whether the masking noise (Nn) causes OM or not.
b) Identify the level of the BC test signal (BT) that is barely heard by the participant, and obtain the BC threshold measured in the test ear with Nn (BLn).
c) Determine whether the measured BC threshold is the true or false (SH or OM) threshold.
d) Estimate the range of the true BC threshold possible in the test ear.

(1) N1 = 80 dB HL (= AL*); α1 = N1 − AR* = 35 dB.

N1 of the level equal to AL* is presented to the non-test ear (**Fig. 5-12 [a]**).

a) OM level [1] = N1 − IaA = 80 (dB HL) − 60 (dB) = 20 dB HL (= BLs ≤ BL*).
N1 does not cause OM and is MNnpo.

b) BL-CH level [1] = mBR1 + IaB = 35 (dB HTL) + 0 (dB)
= 35 dB HL (< BL* = 40 dB HTL).
As the level of BT is raised from 20 dB HL (= BLs) in 5-dB steps, the participant will barely hear the initial BC test signal (BT1) of 35 dB HL (**Fig. 5-12 [a]**). Then, the BC threshold measured in the test ear with N1 (BL1) is 35 dB HTL (**Fig. 5-12 [b]**).

c) The examiner cannot be sure whether BL1 of 35 dB HTL is the true or SH threshold. This is because, whenever the true BC threshold in the test ear is higher than or equal to 35 dB HTL, the participant will always barely hear BT1 of 35 dB HL that is equal to the BL-CH level [1].

d) Since the amount of the BC threshold elevation in the test ear with N1 (θ1) is 15 dB (θ1 = BL1 − BLs = 15 dB), the examiner realizes that BL* is ≥ 35 dB HTL (**Fig. 5-12 [b]**).

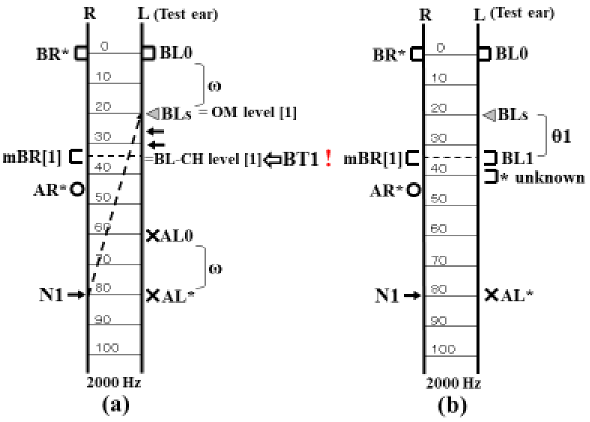


Figure 5-12 N1 = 80 dB HL (= AL*)

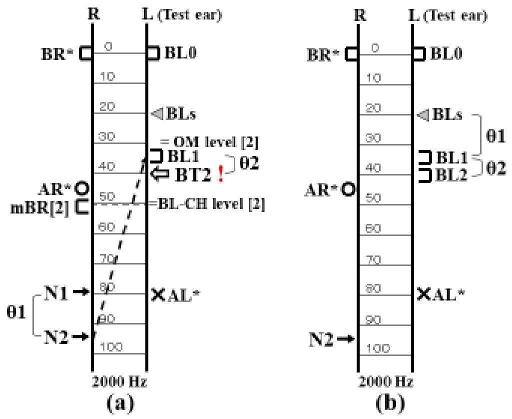


Figure 5-13 N2 = 95 dB HL (= N1 + θ1)

(2) N2 = 95 dB HL (= N1 + θ1), α2 = N2 − AR* = 50 dB.

N2 is N1 plus θ1 (**Fig. 5-13 [a]**).

a) OM level [2] = N2 − IaA = 95 (dB HL) − 60 (dB)
= 35 dB HL (= BL1 ≤ BL*).
N2 does not cause OM and is also MNnpo.

b) BL-CH level [2] = mBR[2] + IaB = 50 (dB HTL) + 0 (dB)
= 50 dB HL (> BL* = 40 dB HTL).
As the level of BT is raised from 35 dB HL (= BT1) in 5-dB steps, the participant will barely hear the second BC test signal (BT2) of 40 dB HL (**Fig. 5-13 [a]**). Therefore, the BC threshold measured in the test ear with N2 (BL2) is 40 dB HTL (**Fig. 5-13 [b]**).

c) Since BT2 of 40 dB HL is lower than the predicted BL-CH level [2] of 50 dB HL, the examiner knows that BT2 is not heard by the non-test inner ear (mBR[2]), that is, the hearing of BT2 is not SH. Therefore, at least theoretically, the true threshold in the test ear has been determined (BL2 = BL*).

(3) N3 = 100 dB HL (= N2 + θ2); α3 = N2 − AR* = 55 dB.

The amount of the BC threshold elevation in the test ear with N2 (θ2) is 5 dB (θ2 = BL2 – BL1 = 5 dB) (cf. **Fig. 5-13 [a]**). N3 is N2 plus θ2 (**Fig. 5-14**).

a) OM level [3] = N3 − IaA = 100 (dB HL) − 60 (dB)
= 40 dB HL (= BL2 = BL* = 40 dB HTL)

N3 is the maximum level of masking noise at which OM does not occur (MN) and the maximum adequate masking noise level (Nmax).

b) The participant will barely hear the third BC test signal (BT3) of 40 dB HL (= BT2). Therefore, the BC threshold measured in the test ear with N3 (BL3) is 40 dB HTL. BL3 is not higher than BL2 (BL3 = BL2).

c) The lack of threshold elevation indicates that SH has not occurred. The examiner can be sure that BL3 is the true BC threshold.

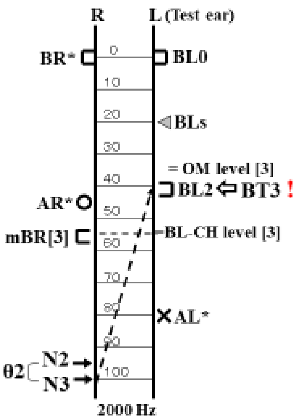


Figure 5-14 N3 = 100 dB HL

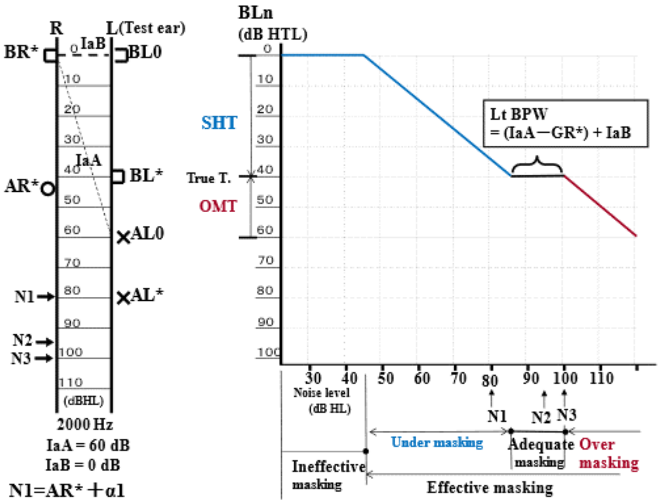


Figure 5-15 MNnpo and BC plateau

5.4-2 The BC plateau in pattern [4]

For BC, the present method using MNnpo is more efficient than the plateau method (**Fig. 5-15**).

5.4-3 Masking procedure for BC of the present method

The above example in pattern [4] is generalized with the following procedure (**Fig. 5-16**). When bilateral apparent AC thresholds differ significantly (e.g., AR0 < AL0, Rt AA gap ≥ 15 dB), then the test ear is the left, poorer ear by AC and the non-test ear is the right, better ear by AC.

The initial masking noise (N1) of the level that is equal to the true AC threshold level in the left (test) ear is presented to the right (non-test) ear:

N1 = [AL*] dB HL.

If the BC threshold measured in the test ear with N1 (BL1) is not higher than BLs (BL1 = BLs), BL1 is the true threshold. If it is elevated, the masking noise level is increased sequentially by the amount of the BC threshold elevation in the test ear with Nn (θn):

Nn+1 = (Nn + θn) dB HL; (n = 1, 2, 3, …).

When the BC threshold measured in the test ear with Nn+1 (BLn+1) is not higher than BLn (BLn+1 = BLn), BLn is the true threshold.

Using the masking noise at the maximum output level of the audiometer, the BC thresholds obtained in the test ear are the limit of measurement. This masking procedure with MNnpo is theoretically the most efficient one (cf. **7-6 [5]**).

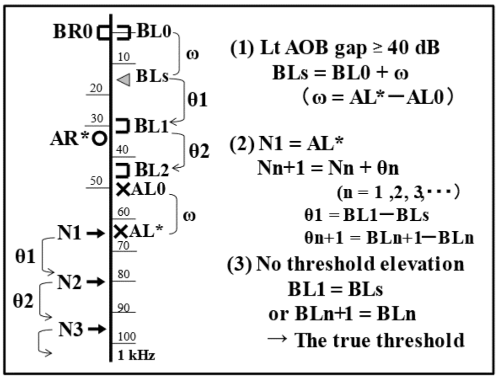


Figure 5-16 Masking procedure for BC-1

5.5 Masking procedure in patterns except for pattern [4]

Masking in patterns except for pattern [4] ([1]–[3], [1’]–[3’]) (**Fig. 5-17**) is considered. In **Fig. 5-18**, the configuration at 4000 Hz (AR0 = AL0) is discussed in Lecture 6.

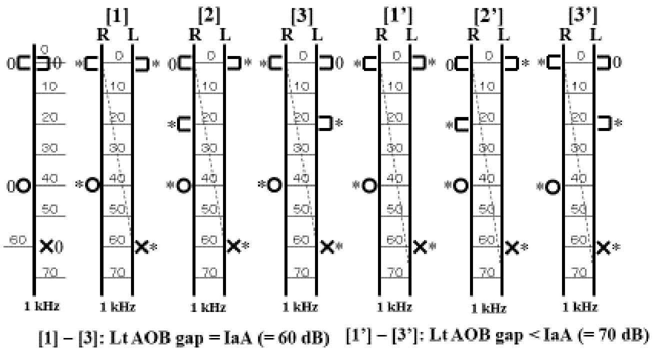


Figure 5-17 Patterns [1]-[3], [1’]-[3’]

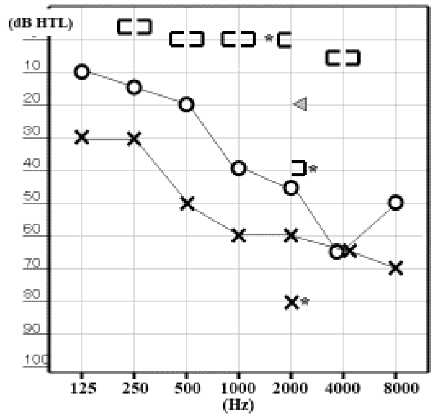


Figure 5-18 Audiogram with adequate masking at 2000 Hz

(1) Pattern [3] at 1000 Hz: Lt AOB gap = IaA.

Let us consider the following pattern [3] in which the true thresholds at 1000 Hz in **Fig. 5-18** are: The right (non-test) ear: BR* = 0 dB HTL, AR* = 40 dB HTL, The left (test) ear: BL* = 30 dB HTL, AL* = 60 dB HTL (= AL0), IaA = 60 dB = Lt AOB gap.

For AC masking, AL0 is anticipated to be possibly the SH threshold because Lt AOB gap = AL0 − BR0 = 60 dB > 40 dB. When masking with N1 (= AL0) in the right ear, the AC threshold measured in the left (test) ear with N1 (AL1) is not elevated (AL1 = AL0; cf. **Fig. 5-5**), therefore, AL0 proves to be the true threshold. At this time, the examiner knows that the configuration is one of the patterns except for pattern [4], but cannot specify the actual pattern (cf. **5.2**).

The basic making procedure for BC masking in patterns except for pattern [4] is the same as the one used in pattern [4] (**Fig. 5-19**). In these patterns (ω = AL* − AL0 = 0 dB), the standard level of the BC threshold is set to the level of the apparent BC threshold in the test ear (BLs = BL0 = BR*).

N1 of 60 dB HL (= AL*) is MNnpo (**Fig. 5-20 [a]**). Then, the BC threshold measured in the test ear with N1 (BL1) is 20 dB HTL, and the amount of the BC threshold elevation in the left ear with N1 (θ1) is 20 dB.

N2 is increased by θ1 dB from N1 (N2 = N1 + θ1 = 80 dB HL). Then, BL2 of 30 dB HTL is obtained and θ2 is 10 dB (**Fig. 5-20 [b]**).

N3 is set to 90 dB HL (= N2 + θ2), and the measured BC threshold is not elevated (BL3 = BL2). Hence, BL3 is considered the true threshold (**Fig. 5-20 [b]**).

The examiner only knows that the IaA value at 1000 Hz is ≥ 60 dB, therefore, he/she cannot determine whether the configuration at 1000 Hz is a pattern [3] or [3’].

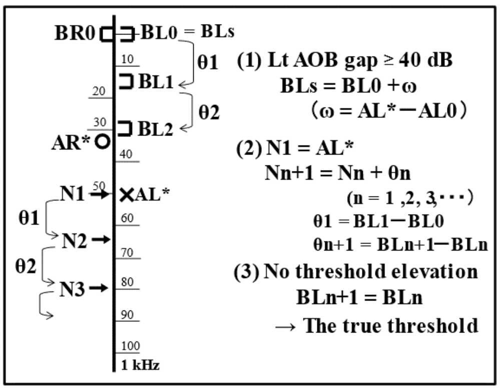


Figure 5-19 Masking procedure for BC-2

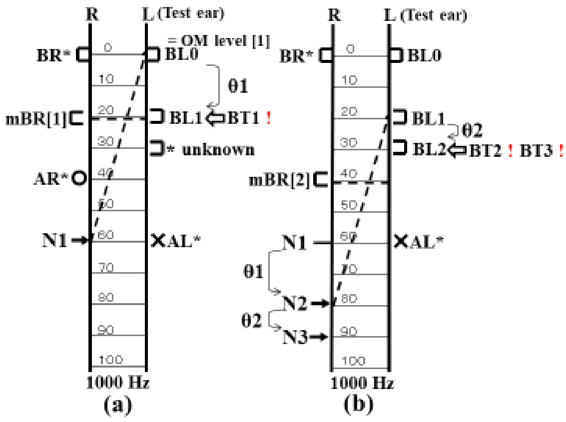


Figure 5-20 Masking for BC in pattern [3]

(2) Pattern [3’] at 250 Hz: Rt AA gap =15 dB ≤ Lt AOB gap < IaA

Let us consider the following pattern [3’] in which the true thresholds at 250 Hz in **Fig. 5-18** are:
The right (non-test) ear: BR* = −5 dB HTL, AR* = 15 dB HTL,
The left (test) ear: BL* = 20 dB HTL, AL* = 30 dB HTL (= AL0), IaA ≥ 40 dB.

Since Lt AOB gap = AL0 − BR0 = 35 dB < 40 dB, AL0 of 30 dB HT is the true threshold. At this time, the examiner knows that this configuration is either the patterns [1’], [2’], or [3’] (cf. **Fig. 5-17**). Since Lt AOB gap = 35 dB ≥ 15 dB, masking for the left BC is needed (cf. **4.4-2**). The initial masking noise level is set to the maximum level of masking noise at which OM does not occur in any case, assuming the minimum IaA value of 40 dB (Nx) (**Fig. 5-21 [a]**):

N1 = Nx = BR0 + min IaA = −5 (dB HTL) + 40 (dB) = 35 dB HL.

Then, the BC threshold measured in the test ear with N1 (BL1) of 20 dB HTL (> BL0) is obtained, and the amount of the BC threshold elevation in the test ear with N1 (θ1) is 25 dB.

N2 is increased by θ1 from N1 (N2 = N1 + θ1 = 60 dB HL). Then, the measured BC threshold is not elevated (BL2 = BL1). Therefore, BL2 is considered the true threshold (**Fig. 5-21 [b]**). The examiner knows that this configuration is a pattern [3’] (cf. **Fig. 5-17**).

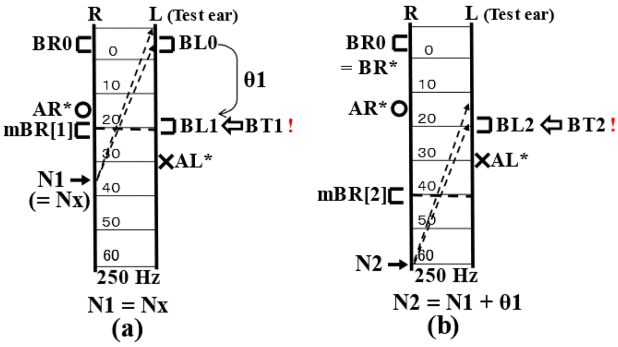


Figure 5-21 BC masking in the case where Lt AOB gap < 40 dB

5.6 Masking for AC at 125, 8000 Hz

BC thresholds at 125 Hz and 8000 Hz are not measured. At 125 Hz in **Fig. 5-18** on the preceding page, even if the true BC threshold in the right ear (BR*) is −5 dB HTL,

Lt AOB gap = AL0 − BR0 = 30 (dB HTL) − (−5) (dB HTL) = 35 dB < 40 dB.

Therefore, masking for the left AC is not needed. At 8000 Hz in **Fig. 5-18**, the need for AC masking cannot be estimated. In this case, we cannot help masking the better ear by AC (the right ear). Although the BC thresholds are unknown, N1 (= 70 dB HL) does not cause OM (N1 = MNnpo, **Fig. 5-22 [a]**, cf. **5.2**, **5.3-3**). If the true AC threshold in the left ear (AL*) of 90 dB HTL is obtained as in **Fig. 5-22 [b]**, the configuration proves to be a pattern [4]. **Fig. 5-23** shows the audiogram with adequate masking.

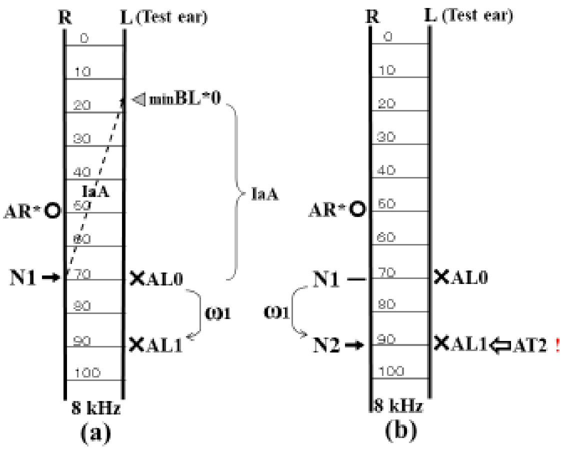


Figure 5-22 Masking at 8000 Hz

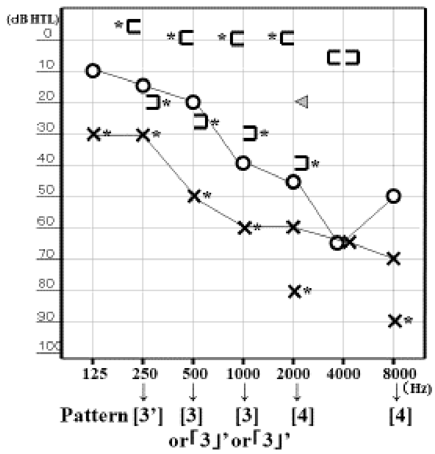


Figure 5-23 Audiogram with adequate masking

**** Further note****

*) In **Fig. 5-23**, the right ear is estimated to be a sensorineural deafness from the AC hearing patterns. The audiogram is created to show the patterns of audiometric configurations in one figure.

5.7 The true AB gap of the non-test ear and a singular level

Fig. 5-24 (a) shows the audiometric configuration at 1000 Hz in which the apparent AC and BC thresholds in the right ear are both true thresholds:

The right ear: AR0 = AR* = 45 dB HTL, BR0 = BR* = 0 dB HTL, GR* = 45 dB (< IaA).

When N1 of 80 dB HL is presented to the right ear, the BC threshold measured in the left (test) ear with N1 (BL1) is in the range between the OM level [1] and BL-CH level [1]:

$$\text{OM level [1]} \leq \text{BL1} \leq \text{BL-CH level [1]}.$$

The range width (dB) is written as

$$\text{BL-CH level [1]} - \text{OM level [1]} = \{(\text{N1} - \text{GR*})\} + \text{IaB}\} - (\text{N1} - \text{IaA})$$
$$= (\text{IaA} - \text{GR*}) + \text{IaB}.$$

If the IaB value is assumed to be 0 dB,

$$\text{BL-CH level [1]} - \text{OM level [1]} = \text{IaA} - \text{GR*}.$$

The equation indicates that as the true AB gap of the right (non-test) ear (GR*) grows larger, the range width of BL1 becomes smaller. Furthermore, as shown in **Fig. 5-24 (b)**, when GR* is equal to IaA (GR* = IaA), the OM level [1] and BL-CH level [1] become the same level. In this lecture series, this level is termed a singular level.

a) When the true BC threshold in the left (test) ear (BL*) is lower than the singular level, BL1 is the OM threshold (**Fig. 5-24 [b]**).

b) When BL* is higher than that level, BL1 is the SH threshold (**Fig. 5-24 [c]**).

c) Only when BL* is equal to that level, BL1 is the true threshold (Lt BPW = 0 dB). However, the 0-dB plateau cannot be identified.

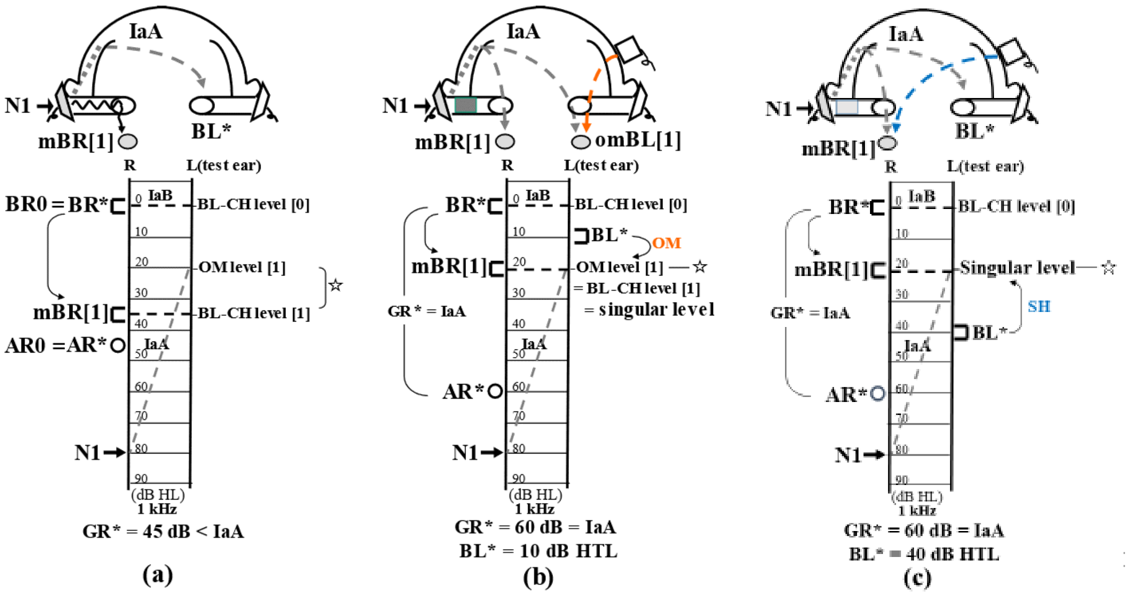


Figure 5-24 True AB gap of the non-test ear and singular level

Theoretically, if the true AB gap of the non-test ear is equal to IaA, and the IaB value is 0 dB, then the true BC threshold in the test ear cannot be determined by using BC test signals, because the singular level occurs in the test ear. Namely, masking for BC becomes impossible.

Clinically, even when there is a little difference between IaA and GR* (IaA − GR* = 5 or 10 dB), masking for BC becomes difficult or impossible. The clinical configurations in which GR* is equal to IaA are rare cases such as congenital atresia of the external auditory canal, and ossicular discontinuity, in which cases effective masking occurs via the direct-converted BC pathway (cf. **2.2-3 [2]**). This issue will be discussed in detail in Lecture 6.

**** Further note ****

) When IaB > 0 dB, BL-CH level [1] − OM level [1] = (IaA − GR) + IaB. Significance of the IaB value is discussed in **Supplement 6**.

*) In lecture 7, a BC masking window is defined. The singular level means that the BC masking window has closed completely (cf. **7.6 [4]**).

*) Even if the true AB gap of the non-test ear is not equal to IaA, as fa as the apparent AB gap of the non-test ear is equal to IaA (GR0 = IaA), masking for BC becomes impossible (cf. **6.1**).

5.8 Significant AA gaps

(1) The application of the present method

The difference between the apparent AC thresholds in both ears at some frequency is referred to as an AA gap (cf. **4.3**). Theoretically, an AA gap of only 5 dB is significant. However, clinically, it is not significant considering the measurement errors. In this lecture series, AA gaps more than or equal to 15 dB are supposed to be significant. If the right, better ear by AC is set to be the non-test ear (the right ear is the masked ear), audiometric patterns corresponding to Rt AA gaps are as follows:

Rt AA gap ≥ 15 dB: Patterns [1] – [4], [1'] – [3'] (**Fig. 5-25**).

0 dB ≤ Rt AA gap ≤ 10 dB: Patterns [5] – [7], [5'], [6'] (cf. **Fig. 5-2**).

The present method applies to cases in which Lt AOB gap ≥ 40 dB and Rt AA gap ≥ 15 dB. The initial masking noise presented to the right ear (Rt N1) is as follows (**Table 5-2**):

Rt N1 for AC = [AL0] dB HL,

Rt N1 for BC = [AL*] dB HL; (AL* ≥ AL0).

When 15 dB ≤ Lt AOB gap < 40 dB, masking for the left AC is not needed. Then, regardless of AA gaps, N1 for BC is set to Nx (**Table 5-2**, cf. **Fig. 5-21 [a]**):

Rt N1 for BC = Rt Nx = (BL0 + min IaA) dB HL.

The present method cannot be applied to the configurations with the AA gaps of 0, 5, and 10 dB. The plateau method should be used, as is described in Lecture 6.

Table 5-2 Criteria for AC and BC masking and initial masking noises

	AC masking	BC masking
1. 40 dB ≤ Lt AOB gap, 15 dB ≤ RtAA gap	N1 = AL0	N1 = AL*
2. 15 dB ≤ Lt AOB gap < 40 dB	Not needed	N1 = Nx
3. 0 dB ≤ Lt AOB gap ≤ 10 dB	Not needed	Not needed

(2) Patterns in which masking for BC in the poorer ear by AC is needed

When AA gaps are significant, theoretically (i.e., IaB = 0 dB and measurement errors = 0 dB, cf. Lecture 0), the true AC and BC thresholds in the left, poorer ear by AC (AL*, BL*) can be always determined using the present method. Especially in patterns [3], [3'], and [4], all true thresholds can be obtained (BL* > BR0 = BR*) (**Fig. 5-25**). Therefore, masking for BC in the poorer ear by AC is not needed.

By contrast, in patterns [1], [2], [1'], and [2'], the apparent BC threshold in the left ear (BL0) is equal to the true BC threshold (BL0 = BL*), therefore, the apparent BC threshold in the right ear (BR0) is not determined whether it is the true or SH threshold. Hence, masking the left ear, we should obtain the true BC threshold in the right ear (masking for the right BC is needed; cf. **2.4 [4]**). In patterns [1] and [2], since the true AB gap of the left ear is equal to IaA (GL* = IaA), the true BC threshold in the right ear (BR*) cannot be determined (cf. **5.7**). This will be discussed in Lecture 6.

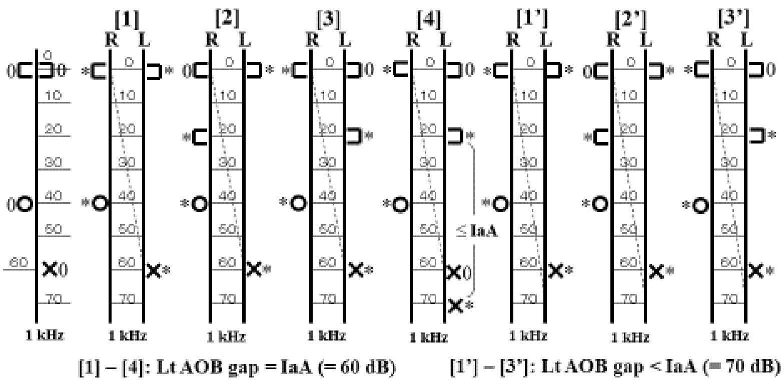


Figure 5-25 Audiometric configuration patterns (Rt AA gap ≥ 15 dB)

**** Further note ****

*) If the participant's response has high accuracy, an AA gap of 10 dB may be significant.

5.9 Points of attention

(1) Two challenges of the noises for the present method

Even if the test ear has the maximum AB gap, theoretically the noises of the present method never cause OM, and have the advantage of the maximum masking efficiency (cf. **7.6 [5]**). However, there are two challenges in the clinical situation.

a) The one is the noise load on the non-test ear.

The audiometric configuration in **Fig. 5-26 (a)** is a case in which the Rt AA gap is small (15 dB), and three noise steps are required to establish the true AC threshold in the left ear (AL* = 80 dB THL). By contrast, when the Rt AA gap is large, the true threshold can be determined with fewer noise steps. For example, in a case in which the Rt AA gap is 50 dB and AL* is 80 dB THL as in **Fig. 5-26 (b)**, when masking with N1 (= MNnpo = 60 dB HL) in the right ear, clearly the AC threshold measured in the left ear (AL1) of 80 dB HTL is not an SH threshold. At this time, the noise (N1) puts an unnecessary extra load on the non-test ear, which should be avoided clinically. Its countermeasure will be addressed in Lecture 8.

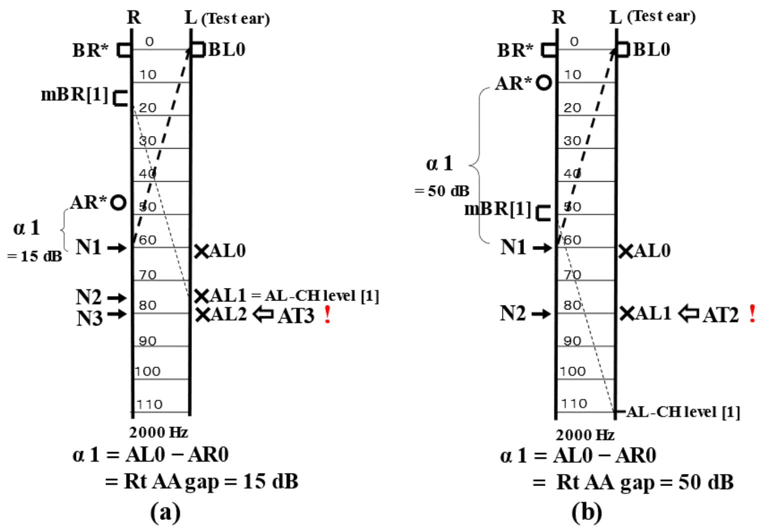


Figure 5-26 Challenge point of MNnpo 1

b) The other is an issue of OM in the test ear.

In the configurations in which the test ear has the maximum AB gap (GL* = IaA) such as patterns [1] and [2] (**Fig. 5-27**), if the boundary condition for OM is not true in a clinical setting, then N1 of MNnpo causes OM (cf. **2.3-2**). Furthermore, although the present masking theory discusses peripheral masking (masking at the level of cochleae), the BC threshold in the test ear might be elevated due to a central masking effect (masking in the auditory central nervous system).

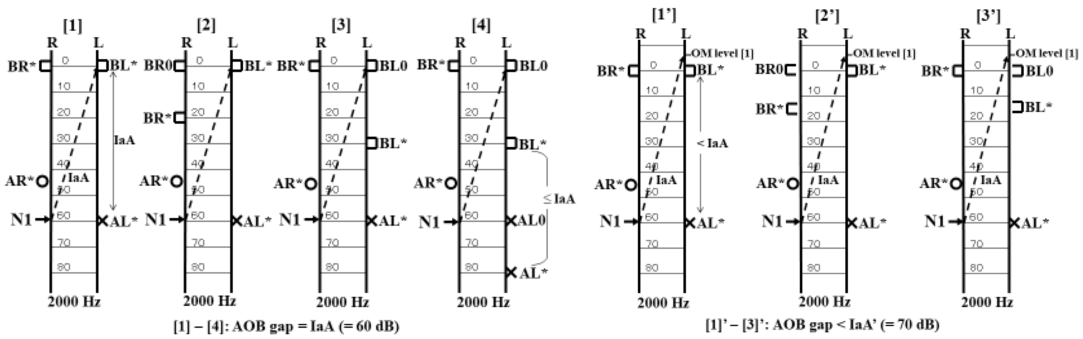


Figure 5-27 Challenge point of MNnpo 2

**** Further note ****

*) MNnpo: Maximum level of masking noise that has no possibility of overmasking

*) MN: Maximum level of masking noise at which overmasking does not occur

(2) Central masking

Even when the masking noises which never cause OM are presented to the non-test ear, the BC threshold in the test ear might be elevated. This phenomenon has been termed central masking (Dirks and Norris, 1966). However, since it is not the non-test but test ear where the BC threshold is elevated, the phenomenon should be termed OM according to the definition (cf. **2.3-1**). Therefore, it is termed "central overmasking" in this lecture series (**Table 5-3**, cf. **8.2-2**).

Table 5-3 Peripheral and central masking

	The BC threshold elevation in the non-test ear	The BC threshold elevation in the test ear
Peripheral masking	(Peripheral) effective masking	(Peripheral) overmasking
Central masking	unknown	Central overmasking

(3) Occlusion effects

It can be assumed that when an occlusion effect (OE) is created in the non-test ear at low frequencies, the masking effect is decreased by the OE value. Under this assumption, the initial masking noise level must be increased by that value. In particular, when the effect is created in cases where masking for BC is challenging, the possibility of OM occurs, and masking for BC becomes more difficult. This is a traditional concept (Lloyd & Kaplan, 1978).

The OE is not a factor that makes masking for BC more difficult. It will be discussed in Lecture 10.

(4) Subdivided patterns of patterns [4] and [7]

In patterns [4] and [7] in which the apparent AC threshold in the left, poorer ear (AL0) is the SH threshold, both patterns are subdivided into three patterns (**Fig. 5-28**). Assuming that the side in which the apparent AC thresholds are the SH thresholds is left, the true AB gaps of the left ear (GL*) are as follows:

Pattern [4-0]: GR* < IaA, GL* < IaA　　Pattern [7-0]: GR* = IaA, GL* < IaA
Pattern [4-1]: GR* < IaA, GL* = IaA　　Pattern [7-1]: GR* = IaA, GL* = IaA
Pattern [4-2]: GR* < IaA, CHL　　Pattern [7-2]: GR* = IaA, CHL

where CHL is the complete hearing loss.

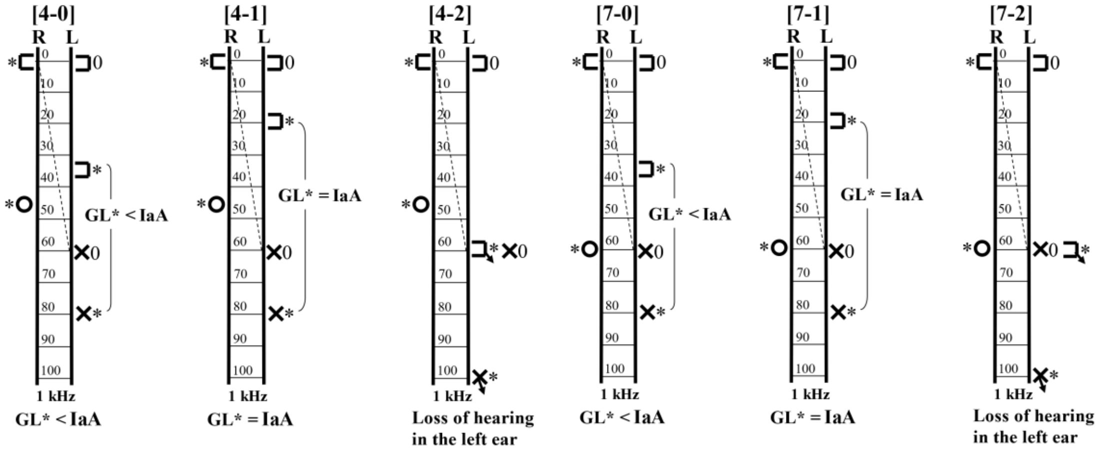


Figure 5-28 Subdivided patterns of patterns [4] and [7]

**** Further note ****

*) The central overmasking values (COM values) are considered as 5 to 15 dB (Lidén et al, 1959).
*) In this lecture series, it is assumed that the maximum output level of the BC test signal is 60 dB HL.

5.10 Summary of Lecture 5

1. When the apparent AC thresholds differ (e.g., AR0 < AL0) and Lt AOB gap = AL0 − BR0 ≥ 40 dB, the apparent AC threshold in the poorer ear (AL0) is possibly the SH threshold. Thus, masking for AC is needed. It is assumed that the right is the non-test, better ear by AC and the left is the test, poorer ear by AC.

2. Given only the information that the true BC threshold in the left (test) ear is higher than or equal to BL0 (BL* ≥ BL0), N1 (= [AL0] dB HL) is the maximum level of masking noise that has no possibility of OM (MNnpo). N1 is theoretically the most efficient noise level.

3. Masking procedure for AC of the present method

The n-th masking noise (Nn, n = 1, 2, 3, …) of the level that is equal to the AC threshold level measured in the left (test) ear with Nn-1 (ALn-1) is presented to the right (non-test) ear (Nn = [ALn-1] dB HL). If the AC threshold measured in the test ear with Nn (ALn) is not higher than ALn-1 (ALn = ALn-1), ALn is the true threshold. If the measured AC thresholds continue to be elevated and the participant does not respond to the AC signal at the limits of the audiometer, then a complete loss of hearing is evidenced.

4. Masking procedure for BC of the present method

The initial masking noise (N1) of the level that is equal to the true AC threshold level in the test ear (N1 = [AL*] dB HL) is presented to the non-test ear. If the BC threshold measured in the test ear with N1 (BL1) is not higher than BLs (i.e., the standard level of the BC threshold in the test ear), BL1 is the true threshold (BL1 = BLs = BL*). If the measured threshold is elevated, the masking noise level is increased sequentially by the amount of the BC threshold elevation in the test ear with Nn (θn): Nn+1 = Nn + θn. When the BC threshold measured in the test ear with Nn+1 (BLn+1) is not higher than BLn (BLn+1 = BLn), BLn+1 is the true threshold. Using the masking noise at the maximum output level of the audiometer, the BC thresholds obtained in the test ear are the limit of measurement.

5. When the true AB gap of the non-test ear is equal to the IaA value (GR* = IaA), assuming that the IaB value is 0 dB, all the effective masking noises create a singular level in the test ear. Therefore, masking for BC becomes impossible.

6. In this lecture series, AA gaps more than or equal to 15 dB are supposed to be significant.

The initial masking noise for AC:

When 40 dB ≤ Lt AOB gap and 15 dB ≤ Rt AA gap, Rt N1 = [AL0] dB HL.

The initial masking noise for BC:

When 40 dB ≤ Lt AOB gap and 15 dB ≤ Rt AA gap, Rt N1 = [AL*] dB HL.

When 15 dB ≤ Lt AOB gap < 40 dB, Rt N1 = Rt Nx = (BL0 + 40) dB HL.

7. MN is the maximum level of masking noise at which OM does not occur:

Rt MN = (BL* + IaA) dB HL.

It is determined when the true BC threshold in the test ear (BL*) and the IaA value have been obtained.

MNnpo is the maximum level of masking noise that has no possibility of OM:

Rt MNnpo = (min BL*n + IaA) dB HL.

It is determined when the minimum level of the true BC threshold possible in test ear with Nn (min BL*n) and the minimum or confirmed value of IaA have been obtained.

Nx is the maximum level of masking noise at which OM does not occur in any case, assuming the minimum IaA value of 40 dB.

Rt Nx = (BL0 + min IaA) = (BL0 + 40) dB HL.

It is determined when neither the true BC threshold in the test ear (BL*) nor the IaA value have been obtained.

Nmax is the maximum adequate masking noise level.

Rt Nmax = (BL* + IaA) dB HL.

Although Nmax is the same equation as MN, it has different meanings. If a plateau is present, Nmax = MN. If no plateau is present, Nmax is absent and MN might be present.