Department of Veterans Affairs

Journal of Rehabilitation Research and Development Vol. 33 No. 4, October, 1996
Pages 355–362

An equivalent input noise level criterion for hearing aids

John H. Macrae, PhD and Harvey Dillon, PhD
National Acoustic Laboratories, Chatswood NSW 2067 Australia

Abstract—The purpose of this project was to establish a maximum acceptable equivalent input noise level (EINL) for hearing aids. It was found that, if the version of the National Acoustic Laboratories (NAL) procedure for selecting the gain and frequency response of hearing aids, which includes modifications for severe and profound hearing loss is used, the EINL criterion can be relaxed for higher gain hearing aids, as a function of the gain of the aid. The relationship between relaxation of the criterion and 2-cc coupler gain is nonlinear, in different amounts, at the various frequencies, so no simple rule can be used to describe the manner in which the criterion can be relaxed.

Key words: *equivalent input noise level, hearing aids, internal noise.*

INTRODUCTION

A hearing aid emits noise even when no external sound enters its microphone. This noise is generated predominantly by the microphone of the aid. The internal noise of an aid is most usefully expressed as the equivalent noise at the input required to produce the same output noise. This equivalent input noise method of measurement enables hearing aids with different gains to be compared without prejudice to higher gain aids, which have higher output noise because of the higher gain applied to the internal noise of the aid. Calculation of the equivalent input noise of an aid basically involves subtraction of the gain of the aid from the internal noise output level of the aid. This is best carried out by measuring the output noise in one-third octave bands and, for each band, subtracting the gain, in decibels (dB), at the band center frequency from band output level, in dB sound pressure level (SPL). The measurements of gain and internal noise output are customarily carried out in a 2-cc coupler (1). The inlet to the microphone of the hearing aid is usually blocked while the internal noise at the output is measured.

The aim of an equivalent input noise level (EINL) criterion for hearing aids is to ensure that, as far as possible, the internal noise of a hearing aid is inaudible to the user or, if it is audible, that it is not objectionable. An internal noise specification for hearing aids was published in NAL Report No. 102 by Dillon and Macrae (2). The experiment that was used to arrive at the specification is described in detail in that report. The criterion is based on the signal-to-noise ratio just acceptable to the majority of a panel of normal-hearing subjects while they were listening to continuous discourse. The derivation involves data concerning the long-term average speech spectrum (LTASS). After the publication of NAL Report No. 102, additional measurements of LTASS were performed. The results were slightly different from those used in the report, so Macrae and Dillon (3) averaged the two sets of results to determine a new LTASS based on 60 talkers and adjusted the equivalent noise level criterion slightly. The criterion is given in Figure 10 and Table 5 of Macrae and Dillon (3).

Dillon and Macrae (2) pointed out that the internal noise criterion can be relaxed somewhat in the low frequency region (typically 500 Hz and below) if a vented earmold is to be used with the hearing aid. If the sound in the ear canal is dominated by sound transmit-

This material is based upon work supported by Australian Hearing Services.

Address all correspondence and requests for reprints to: John H. Macrae, PhD, National Acoustic Laboratories, 126 Greville St., Chatswood NSW 2067 Australia.

ted in through a vent, then noise originating in the hearing aid is of little consequence. For every decibel by which the combined transmission gain (through the aid and the vent) lies above the transmission gain through the aid alone (as modified by the vent, but not including the sound transmitted in through the vent), one decibel can be added to the criterion EINL. As the earmold characteristics are only known when hearing aids are provided to individual clients, a practical approximation for the purposes of type-testing of hearing aids is to relax the criterion by one decibel for every decibel by which the transmission gain of the aid falls below 0 dB when measured in an occluded ear simulator or below −4 dB when measured in a 2-cc coupler. This relaxation is only valid if the hearing aid is to be provided with a vent sufficiently large to transmit sound into the ear canal with minimal attenuation. Data on this have been published by Dillon (4).

Dillon and Macrae (2) and Macrae and Dillon (3) have considered the degree to which the noise criterion can be relaxed for high gain hearing aids. Different conclusions were reached in these two articles as different assumptions were made about the amount of gain likely to be used at each frequency by people with various degrees of hearing loss. This question needs to be readdressed as, based largely on the work of Byrne, Parkinson, and Newall (5), more is now known about the requirements of people with severe and profound hearing losses, and the NAL-R selection procedure (6) has been modified accordingly (7). We will refer to this modification as the NAL-RP procedure.

The present article calculates the extent to which the noise criterion can be relaxed as the gain of the hearing aid, or the degree of deafness of the aid user, increases. We assume that the internal noise criterion can be relaxed whenever it results in the internal noise at the output of the hearing aid not exceeding the threshold of the user of the aid.

METHOD

Data

The data used in the investigation were 700 audiograms obtained from the case records of adults who had been provided with hearing aids by Australian Hearing Services. The records were selected at random from the files of two hearing centers. Where both ears of the client had been provided with hearing aids, both right and left ear audiograms were included in the sample. Sensorineural, conductive, and mixed losses were included in the sample. The number of audiograms with a conductive component was 105/700 (15 percent). Air and bone conduction thresholds were available at octave frequencies from 250 to 4000 Hz for the entire sample.

Procedure

The aim of the project was to set acceptable limits to the EINL of hearing aids on the basis of the sensation level of the internal noise output of the aids when used in accordance with NAL-RP recommendations concerning gain and frequency response. For any one-third octave band, the sensation level of the internal noise of the hearing aid is determined by the internal noise output level relative to the aid user's threshold, measured at, or referred to, the eardrum. The level of the internal noise output in the ear canal is determined by the real ear aided response (REAR) of the hearing aid and, in the NAL-RP procedure, the rear ear insertion response (REIR); therefore, the REAR of the hearing aid is determined by the thresholds of the client.

The REAR can be obtained from the REIR by adding the average real ear unaided response (REUR). In this study, the unaided head surface to eardrum transfer function was used as the REUR because REIR is determined by means of real ear gain analyzers, which measure REIR from a microphone placed on the head surface. The NAL-RP gain and frequency response recommendations are for REIR measured in this manner. The unaided head surface to eardrum transfer function has been measured for a group of 21 adults by Dillon, Storey, and Carter[1] and the group mean values, which were used as the REUR in this study, are given in **Table 1.**

Table 1.
Group mean values of the head surface to eardrum transfer function at one-third octave frequencies from 250 to 4000 Hz.

Frequency (Hz)	Mean (dB)	Frequency (Hz)	Mean (dB)
250	−0.3	1250	4.8
315	0.0	1600	9.7
400	0.0	2000	17.4
500	−0.1	2500	20.0
630	0.4	3150	16.8
800	0.9	4000	12.7
1000	1.2		

[1]Personal communication, December 7, 1995.

The first task, therefore, was to determine the recommended REIRs from the audiograms. For each audiogram, the recommended REIR at each octave frequency from 250 to 4000 Hz was calculated by means of the NAL-RP gain and frequency response procedure, the details of which are given in **Appendix A.** In the case of conductive and mixed hearing losses, one-quarter of the air-bone gap was added to the REIR that would have been required had the loss been purely sensorineural, as recommended by Lybarger (8). In cases where the threshold exceeded the limit of the audiometer, the threshold was assumed to be 5 dB greater than the audiometer limit.

The next task was to determine the relationship between recommended REIR and HTL. In the NAL-RP procedure, the relationship between REIR and HTL at the various frequencies is linear plus a correction term consisting of 5 percent of the sum of the HTLs at 500, 1000, and 2000 Hz, plus additional corrections for clients with severe or profound sensorineural hearing loss, plus the correction for any conductive component. As a result of the various corrections, the REIR recommended for a particular HTL at a particular frequency is not a fixed value, independent of the HTLs at other frequencies or the type of the loss. Consequently, the recommended REIRs as a function of HTLS at the octave frequencies from 250 to 4000 Hz were calculated from the 700 audiograms and polynomial regression curves were fitted to the results. The coefficients for the polynomial regression of REIR on HTL at the intermediate one-third octave frequencies were determined from those at the octave frequencies by interpolation on a logarithmic scale of frequency.

The following calculations were then carried out at each one-third octave frequency from 250 to 4000 Hz. For HTLs from 0 to 120 dB, the associated threshold level at the eardrum was calculated by adding the minimum audible sound pressure level at the eardrum, in dB SPL, as given in Column M of Table 1 in Bentler and Pavlović (9), to the HTL. The typical recommended REAR was determined by calculating the typical recommended REIR, using the appropriate polynomial regression function, and adding the average adult head-surface to eardrum REUR, as given in **Table 1.** The level of internal noise in the ear canal corresponding to the EINL criterion for mild and moderate hearing losses given in Table 5 of Macrae and Dillon (3) was calculated by adding the REAR to the EINL criterion. The sensation level of the noise in the ear canal was then calculated by subtracting the threshold level at the eardrum from the level of internal noise in the ear canal. Whenever the sensation level was negative, after allowing for the uncertainties of predicting REIR from HTL, the EINL was relaxed sufficiently to give 0 dB sensation level. Following this, the REAR values were converted to coupler gain, and the relaxed EINL values were expressed both as a function of HTL and of coupler gain at the user volume control setting, which is usually 15 dB below full-on for BTE hearing aids and 10 dB below full-on for ITE, ITC, and CIC hearing aids.

Macrae and Dillon (3) have pointed out another relevant factor. Some clients with severe hearing loss prefer to use as much as 15 dB more than the recommended REIR and, in this case, it would be inappropriate to relax the EINL criterion. However, on the basis of recent work by Macrae (10) concerning safety limits for amplification by hearing aids, we recommend that clients who have severe sensorineural hearing loss be strongly advised against the use of more than the recommended amount of gain. We have, therefore, omitted this factor from the calculations.

The steps just outlined can be summarized (after some rearrangement) by the following equations:

$$\text{EINL} = \text{Max}(\text{HTL} + \text{MAP} - \text{CG} - \text{Corr} - 15, \text{EINL}_o) \quad [1]$$

where MAP is minimum audible pressure at the eardrum
CG is coupler gain (HA1 2-cc) typically recommended for a hearing loss
Corr is ear canal SPL minus HA1 2-cc coupler SPL
EINL_o is EINL value for mild hearing loss.

If desired, EINL can be expressed totally in terms of coupler gain by estimating HTL from the inverse of the polynomial regression functions shown in **Table 1:**

$$\text{HTL} = (-b + [b^2 - 4.a(c\text{-REIR})]^{0.5})/(2a) \quad [2]$$

where a, b, and c are the polynomial second order, first order and intercept coefficients, respectively, and

$$\text{REIR} = \text{CG} - \text{REUR} + \text{Corr} \quad [3]$$

where REUR is real ear unaided response from the head surface to eardrum.

RESULTS

The regression relationships between recommended REIR and HTL at the octave frequencies proved to be nonlinear, with significant second-order components but with no significant third-order components. The coefficients of the regression functions at the five octave frequencies and the interpolated coefficients at the intermediate one-third octave frequencies are given in **Table 2.** The relationships between recommended REIR and HTL at the octave frequencies from 250 to 4000 are presented in **Figure 1,** which shows that there is considerable spread of actual recommended REIR around typical recommended REIR. In the severe and profound loss range, the actual recommended REIG can exceed the typical recommended REIG by as much as 15 dB. The standard errors of estimate at the various frequencies are given in **Table 3.**

The results of the EINL calculations at 1000 Hz are shown in **Table 4.** If the EINL criterion is not relaxed as HTL increases, the internal noise in the ear canal is far below threshold for HTLs greater than about 60 dB. If the internal noise of hearing aids is to be inaudible for all, or almost all, users of hearing aids with severe hearing loss, the spread of actual REIR around typical REIR for this degree of hearing loss, as illustrated in **Figure 1,** shows that it will be necessary for the internal noise level associated with typical REIR to be about 15 dB below threshold. We can thus allow the noise level in the ear canal and the EINL criterion to increase accordingly for the higher HTLs (as shown by the numbers in brackets).

Table 2.
Coefficients of second order polynomial regression functions relating recommended REIR to HTL at one-third octave frequencies from 250 to 4000 Hz.

	Coefficient		
Frequency (Hz)	Intercept	1st Order	2nd Order
250	0.16	−0.1788	0.007011
315	−0.77	−0.0533	0.006066
400	−1.73	0.0765	0.005089
500	−2.63	0.1998	0.004176
630	−0.67	0.2397	0.003628
800	1.35	0.2832	0.003062
1000	3.24	0.3238	0.002533
1250	1.26	0.3654	0.001979
1600	−0.94	0.4114	0.001367
2000	−2.93	0.4530	0.000813
2500	−0.41	0.3643	0.001262
3150	2.21	0.2725	0.001727
4000	4.91	0.1775	0.002207

REIR = real ear insertion response
HTL = hearing threshold level

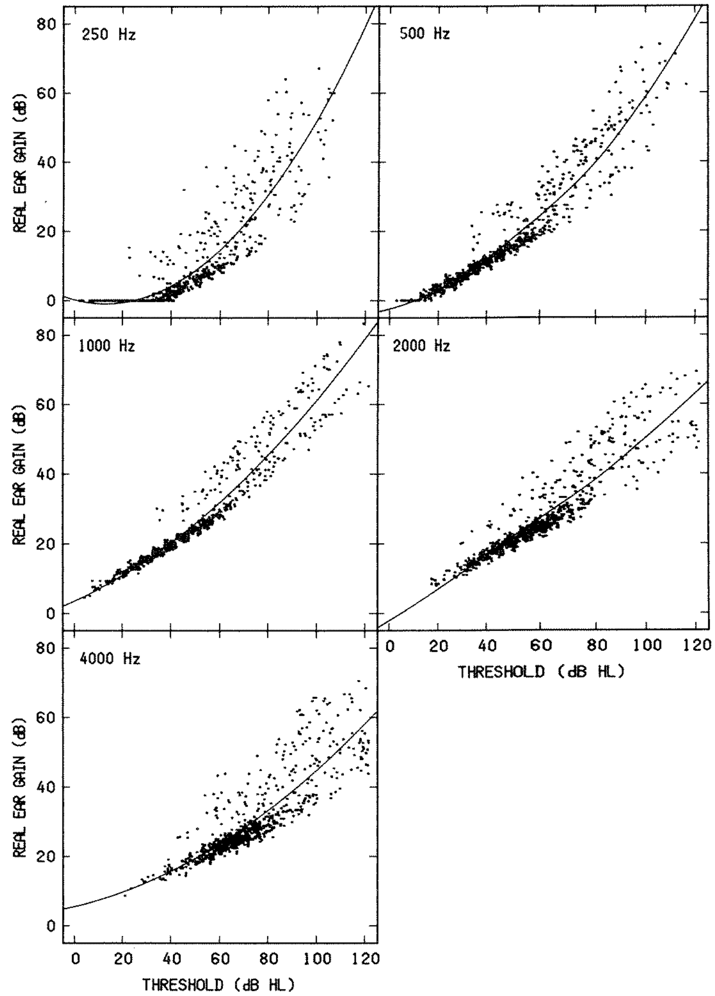

Figure 1.
Scattergram of the relationship between recommended real ear insertion response (REIR) and HTL at octave frequencies from 250 to 4000 Hz.

Table 3.
Standard errors of estimate, in dB, of polynomial regression functions relating recommended REIR to HTL at octave frequencies from 250 to 4000 Hz.

	Frequency (Hz)				
	250	500	1000	2000	4000
Standard Error of Estimate	5.8	4.3	3.9	4.8	5.9

dB = decibel
HTL = hearing threshold level
REIR = real ear insertion response

Table 4.
Relationships at 1 kHz when recommended REAR is provided. Figures in brackets obtained when sensation level of noise is limited to −15 dB.

HTL dB	Threshold at Eardrum dB SPL	REAR dB	Equivalent Input Noise dB SPL	Noise Output Level dB SPL	Noise Sensation Level dB
0	8.3	4.4	17.5	21.9	13.6
10	18.3	7.9	17.5	25.4	7.1
20	28.3	11.9	17.5	29.4	1.1
30	38.3	16.4	17.5	33.9	−4.4
40	48.3	21.4	17.5	38.9	−9.4
50	58.3	27.0	17.5	44.5	−13.8
60	68.3	33.0	17.5 (20.3)	50.5 (53.3)	−17.8 (−15)
70	78.3	39.5	17.5 (23.8)	57.0 (63.3)	−21.3 (−15)
80	88.3	46.6	17.5 (26.7)	64.1 (73.3)	−24.2 (−15)
90	98.3	54.1	17.5 (29.2)	71.6 (83.3)	−26.7 (−15)
100	108.3	62.2	17.5 (31.1)	79.7 (93.3)	−28.6 (−15)
110	118.3	70.7	17.5 (32.6)	88.2 (103.3)	−30.1 (−15)
120	128.3	79.8	17.5 (33.5)	97.3 (113.3)	−31.0 (−15)

dB = decibel
HTL = hearing threshold level
REAR = real ear aided response
SPL = sound pressure level

Table 5 repeats the HTL, REAR, and relaxed EINL data of **Table 4.** It also shows the corresponding coupler gain values at 1000 Hz. The 2-cc coupler gain values were obtained from the REAR values by subtracting the eardrum to 2-cc coupler difference given in column F of Table 1 in Bentler and Pavlović (9). At this frequency, the EINL criterion can be progressively relaxed for hearing aids with gain greater than about 44 dB. **Figure 2** shows the EINL criterion at the octave frequencies from 250 to 4000 Hz as a function of HTL. **Table 6** gives the maximum acceptable EINL as a function of HA1 2-cc coupler gain at the user volume control setting for all the frequencies included in the calculations. This table was derived by calculating the acceptable EINL and coupler gain for HTLs in steps of 1 dB and then obtaining the acceptable EINLs corresponding to coupler gain values in steps of 5 dB by interpolation. If the EINL criterion is required at coupler gains in between those presented in **Table 6,** it can be obtained from the values given in the tables by linear interpolation.

Table 5.
Relationships at 1 kHz between HTL, recommended REAR, HA1 2-cc coupler gain at user volume control setting and maximum acceptable EINL.

HTL dB	REAR dB	Gain dB	EINL dB SPL
0	4.4	−0.8	17.5
10	7.9	2.7	17.5
20	11.9	6.7	17.5
30	16.4	11.2	17.5
40	21.4	16.2	17.5
50	27.0	21.8	17.5
60	33.0	27.8	20.3
70	39.5	34.3	23.8
80	46.6	41.4	26.7
90	54.1	48.9	29.2
100	62.2	57.0	31.1
110	70.7	65.5	32.6
120	79.8	74.6	33.5

dB = decibel
EINL = equivalent input noise level
HTL = hearing threshold level
REAR = real ear aided response
SPL = sound pressure level

DISCUSSION

The EINL criterion has two main uses. The first is in specifications and type-testing of hearing aids. Manufacturers and purchasers of hearing aids must be able to specify the performance requirements for various hearing aid models, and must carry out type-testing in order to assess whether the specifications are met. The second

Journal of Rehabilitation Research and Development Vol. 33 No. 4 1996

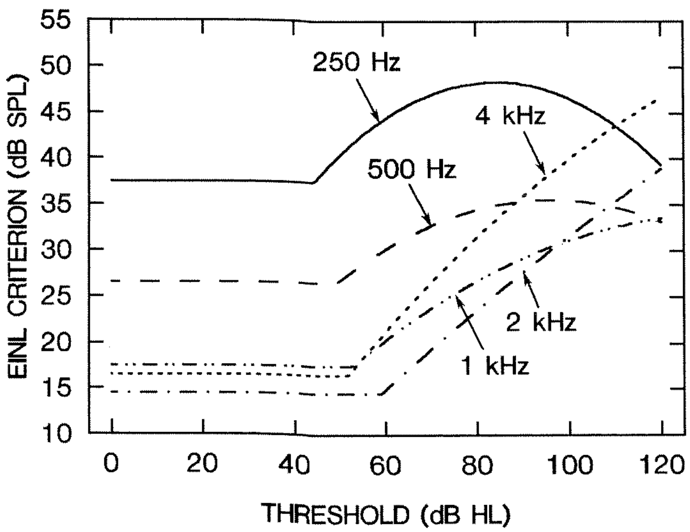

Figure 2.
Equivalent input noise level (EINL) criterion as a function of HTL at octave center frequencies from 250 to 4000 Hz.

use is in testing individual hearing aids during the process of repair or maintenance, in order to ensure that the internal noise output of the aid is acceptable.

The results of the calculations show that, if the NAL-RP procedure for selecting the gain and frequency response of hearing aids is followed, the EINL criterion can be relaxed as a function of the gain of the aids. **Table 6** shows that the relationship between relaxation of the EINL criterion and 2-cc coupler gain is nonlinear, in different amounts, at the various frequencies, so no simple rule, covering all frequencies, or even a set of simple rules, covering different frequency ranges, can be used to describe the manner in which the criterion can be relaxed.

Figure 3 illustrates the relationship between the EINL criterion and HA1 2-cc coupler gain for the octave frequencies from 250 to 4000 Hz. The relaxation begins at a coupler gain of about 35 dB at 2000 Hz but begins at about 15 dB at 500 Hz and about 0 dB at 250 Hz. The noise criterion is relaxed by the greatest amount for the high frequencies and by the least amount for the lowest frequencies. In fact, at 250 Hz, the relaxation actually reverses for profound losses. These trends occur because, in the NAL-RP procedure, gain at the higher frequencies increases less rapidly with hearing loss than does gain at the lower frequencies, in accordance with **Table A2** of **Appendix A,** and as shown in **Figure 1.** Once the noise at the output of the hearing aid decreases below threshold, however, the maximum acceptable output noise level increases on a dB for dB basis with

Table 6.
Acceptable EINL at $^1/_3$ octave band center frequencies from 250 Hz to 4 kHz, as a function of HA1 2-cc coupler gain of the hearing aid at the user volume control setting (15 dB below full-on for BTE hearing aids or 10 dB below full-on for ITE, ITE and CIC aids).

	One-Third Octave Band Center Frequency (Hz)												
Gain (dB)	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**
0	37.5	33.5	30.0	26.5	23.0	20.0	17.5	16.0	15.0	14.5	14.5	15.5	16.5
5	40.7	33.5	30.0	26.5	23.0	20.0	17.5	16.0	15.0	14.5	14.5	15.5	16.5
10	44.1	36.9	30.0	26.5	23.0	20.0	17.5	16.0	15.0	14.5	14.5	15.5	16.5
15	46.3	39.6	32.9	27.7	23.0	20.0	17.5	16.0	15.0	14.5	14.5	15.5	16.5
20	47.5	41.3	35.2	30.1	25.3	20.2	17.5	16.0	15.0	14.5	14.5	15.5	16.5
25	48.1	42.5	36.7	32.0	27.7	23.3	18.6	16.0	15.0	14.5	14.5	15.5	22.4
30	48.4	43.1	37.8	33.4	29.6	25.8	21.6	18.9	15.6	14.5	14.5	15.7	28.0
35	48.2	43.4	38.4	34.4	31.1	27.9	24.1	21.9	19.1	14.5	14.6	20.9	32.6
40	47.8	43.3	38.8	35.1	32.2	29.5	26.2	24.5	22.4	17.7	19.1	25.4	36.5
45	47.1	43.0	38.8	35.4	33.0	30.8	28.0	26.8	25.5	21.5	23.3	29.4	39.9
50	46.2	42.4	38.6	35.6	33.6	31.8	29.5	28.8	28.2	25.0	27.1	32.9	42.7
55	45.2	41.7	38.2	35.5	33.9	32.6	30.7	30.5	30.7	28.5	30.6	36.1	45.2
60	43.9	40.7	37.6	35.2	34.0	33.2	31.7	32.1	33.0	31.7	33.8	38.9	47.3
65	42.6	39.6	36.8	34.8	33.9	33.5	32.5	33.3	35.0	34.7	36.8	41.3	
70	41.1	38.4	35.9	34.2	33.7	33.7	33.1	34.5	37.0	37.5	39.5		

BTE = behind-the-ear
ITE = in-the-ear
CIC = completely-in-the-canal
dB = decibel
EINL = equivalent input noise level

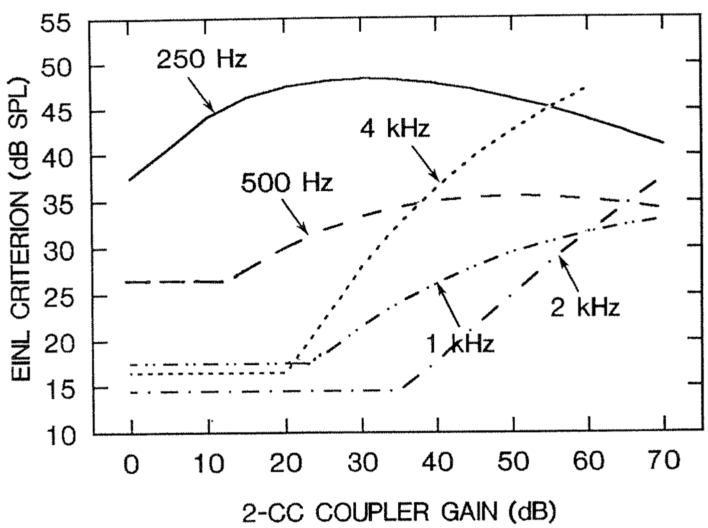

Figure 3.
Equivalent input noise level (EINL) criterion as a function of HA1 2-cc coupler gain at octave center frequencies from 250 to 4000 Hz.

HTL. Consequently, for high frequency sounds, the rising acceptable output noise and less rapidly rising coupler gain combine to give a rising acceptable EINL. For profound losses and low frequency sounds, the typically recommended REAR actually increases by more than 1 dB for every dB of HTL.

The basis of the relaxation is that internal noise output of the hearing aid should remain at or below the threshold of the user. It is possible that noise at threshold can contribute to masking of wanted signals if the internal noise output combines with some other external masker. We believe that our criterion for relaxation is reasonable for two reasons. First, separate maskers appear to have less additive effects for listeners with impaired hearing than they do for listeners with normal hearing (11). Second, by allowing a 15 dB margin to compensate for the spread of actual recommended REIR around typical REIR, we have ensured that the internal noise is 5 dB or more below threshold for the vast majority of users of hearing aids and more than 15 dB below threshold for most users (see **Figure 1**).

The acceptable EINL values given in **Table 6** are only relevant to hearing aids with "linear" amplification and are not appropriate for hearing aids with wide-range dynamic compression. EINL criteria are required for compression hearing aids but fitting procedures are not yet sufficiently well-developed for these types of hearing aids to enable the necessary calculations to be carried out.

CONCLUSION

The results lead to the conclusion that the EINL criterion can be relaxed as function of the 2-cc coupler gain of hearing aids with "linear" amplification, as long as the aid is to be fitted and used in accordance with the recommendations of the NAL-RP procedure for selecting the gain and frequency response of hearing aids.

APPENDIX A

In the NAL-RP procedure for selecting the gain and frequency response of hearing aids, the recommended real ear insertion response (REIR) at a particular frequency is given, for sensorineural hearing loss, by the formula

$$\text{REIR}(f) = X + 0.31\ \text{HTL}(f) + K(f) + P(f)$$

where

REIR(f) is recommended real ear insertion response, in dB
HTL(f) is hearing threshold level, in dB HL
K(f) is a constant with the values given in Table A1
P(f) is a correction for profound hearing loss, the values of which depend on HTL at 2000 Hz and are given in Table A2

$X = 0.05\ (\text{SUM})$ for $\text{SUM} \le 180$

$X = 0.05\ (\text{SUM}) + 0.2\ [(\text{SUM} - 180)/3]$ for $\text{SUM} > 180$

$\text{SUM} = \text{HTL}_{500} + \text{HTL}_{1000} + \text{HTL}_{2000}$

Table A1.
Values of the additive constant K(f).

	Frequency (Hz)									
	250	500	750	1000	1500	2000	3000	4000	6000	8000
K(f)	−17	−8	−3	+1	+1	−1	−2	−2	−2	−2

Table A2.
Values of the correction P(f) for profound hearing loss, as a function of HTL at 2000 Hz.

	Frequency (Hz)									
HTL2k	250	500	750	1000	1500	2000	3000	4000	6000	8000
<95	0	0	0	0	0	0	0	0	0	0
95	4	3	1	0	−1	−2	−2	−2	−2	−2
100	6	4	2	0	−2	−3	−3	−3	−3	−3
105	8	5	2	0	−3	−5	−5	−5	−5	−5
110	11	7	3	0	−3	−6	−6	−6	−6	−6
115	13	8	4	0	−4	−8	−8	−8	−8	−8
120	15	9	4	0	−5	−9	−9	−9	−9	−9

HTL = hearing threshold level.

REFERENCES

1. American National Standards Institute. Method for coupler calibration of earphones. ANSI S3.7-1973. New York: American National Standards Institute, 1973.
2. Dillon H, Macrae JH. Derivation of design specifications for hearing aids. National Acoustic Laboratories Report No. 102, 1984.
3. Macrae JH, Dillon H. Updated performance requirements for hearing aids. J Rehabil Res Dev 1986:23:41–56.
4. Dillon H. Allowing for real ear venting effects when selecting the coupler gain of hearing aids. Ear Hear 1991:12:406–16.
5. Byrne D, Parkinson A, Newall P. Modified hearing aid selection procedures for severe/profound hearing losses. In: Studebaker GA, Bess FH, Beck LB (eds.) The Vanderbilt hearing aid Report II, 295–300. Maryland: York Press, 1991.
6. Byrne D, Dillon H. The National Acoustic Laboratories' (NAL) new procedure for selecting the gain and frequency response of a hearing aid. Ear Hear 1986:7:257–65.
7. Hodgson F, Dillon H. Modified hearing aid gain and frequency response requirements for severe/profound hearing loss. Audiology Circular 1989/23. Sydney: National Acoustic Laboratories, 1989.
8. Lybarger SF. Simplified fitting system for hearing aids. Canonsburg, PA: Radioear Corporation, 1963.
9. Bentler RA, Pavlović CV. Transfer functions and correction factors used in hearing aid evaluation and research. Ear Hear 1989:10:58–63.
10. Macrae JH. Safety aspects of amplification for severe/ profound hearing loss. Aust J Audiol 1995:17: 27–37.
11. Oxenham AJ, Moore BCJ. Additivity of masking in normally hearing and hearing-impaired subjects. J Acoust Soc Am 1995:98:1921–34.