CLINICAL MEASUREMENTS OF THE AUDITORY DYNAMIC RANGE AND THEIR RELATION TO FORMULAS FOR HEARING AID GAIN

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ABSTRACT

A review is made of the results obtained in the measurement of auditory dynamic ranges from 508 adult hearing-impaired ears, tested in a clinical setting during a four-year period. The procedures used in these measurements have been described as part of a previously published hearing aid selection procedure (Pascoe, 1978 and 1986). These results include the group's mean judgements of comfortable loudness and of threshold of discomfort in reference to Hearing Level, as well as the range of standard deviations for each of those means. Data for four frequencies and for Hearing Levels between 0 and 120 dB HL is presented. A comparison is made between these measurements and the application of various "threshold-based" formulas for the selection of hearing aid gain, frequency response, and maximum power output, thus exploring the validity of their use.

INTRODUCTION

Measurements of comfortable and uncomfortable loudness related to Hearing Level have been described previously (Kamm, et al, 1978, Leeds, 1983). The results presented in this paper do not introduce new relationships between various Hearing Levels and their typical auditory dynamic ranges but serve to reinforce the validity of previous results by contributing a larger data base (508 ears). In general, the results presented here strongly support the concept that individual supra-threshold relationships cannot be predicted from threshold levels without introducing the possibility of significant error (Hawkins, et al., 1987). However, mean MCL and UCL or LDL values do show consistent relationships that seem to be the basis for the formulation of gain and frequency response hearing aid parameters, such as appear in various "threshold-based" schemes.

The use of "threshold-based" formulas for the selection of gain is based on the assumption that there are systematic relationships between thresholds of detection and judgements of comfort or preference, as well as with judgements of discomfort or limits of tolerance. Furthermore, a second assumption is that supra-threshold measurements are unreliable and time-consuming, as well as sometimes unobtainable, whereas the thresholds of detection are easier to obtain, more reliable and time-efficient.

The most commonly known formula, sometimes called the "half-gain" rule, has been in use for over 40 years (Lybarger, 1978). This rule states that hearing impaired listeners tend to select an over-all gain that is one-half of their average Hearing Level in dB HL. The validity of this relationship has been supported both empirically and through the results of actual measurements (Lybarger, 1963; Brooks, 1973; Berger, et al, 1980).

An evident implication of the above rule is that the desired output levels delivered by a gain that is one-half of the listener's loss fall within the listener's comfortable range. Whether the input related to this amplification is the speech received from others, the listener's own speech, or a combination of these and environmental noise, is not specified.

Several formulas have extended the "half-gain" rule to various individual frequencies, thus generating desired frequency responses. Among these, the Berger Formula (Berger, et al, 1977), the formulas developed by the Australian National Acoustic Laboratories (NAL) (Byrne, et al. 1986 and Byrne, 1988), and POGO (McCandless and Lyregaard, 1983) are well-known. These formulas also introduce corrections that take into consideration the long-term average speech spectrum as well as average coupler-to-real ear differences. The effects of low-frequency environmental noise are also considered. The more recent NAL formula (Byrne, 1988) combines the "half-gain" rule and a "third-slope" rule to achieve slight variations of the "half-gain" ratio in response to differences in audiometric slope.

Another exploration of the gain vs threshold relationships includes the "one-third to two-thirds" rule (Libby, E.R., 1986). Formulas that recommend less than the "1/2 rule" have been supported by recent findings (Clasen, et al, 1987); this investigation found that the majority of their patients used less amplification than was suggested by the POGO formula.

In general, all of these formulas assume that the gain and frequency response selected will deliver most of the input speech-spectrum into the listener's range of comfortable hearing.

AUDITORY DYNAMIC RANGE MEASUREMENT PROCEDURES

From the stored data gathered from individuals that purchased hearing aids during the last four years at the Central Institute for the Deaf, Hearing Clinic, and for whom complete auditory dynamic range measurements were available, mean comfort and mean thresholds of discomfort were analysed in relation to Hearing Level. Data obtained for four frequencies (500, 1000, 2000, and 4000 Hz) and for Hearing Levels between 0 and 120 dB HL was tabulated.

The procedures used for obtaining both the threshold and supra-threshold information have been described previously (Pascoe, 1986). In essence, the listeners heard pulsed tones under earphones and saw a red light simultaneously. They were instructed to push one of the ten labelled response buttons in front of them. These buttons are placed vertically, with a "NOTHING" button at the bottom and a "TOO LOUD" one at the top. There are three "SOFT" buttons (yellow), three "OK" buttons (green), and three "LOUD" ones (red), including the above mentioned "TOO LOUD". (See Fig. 1)

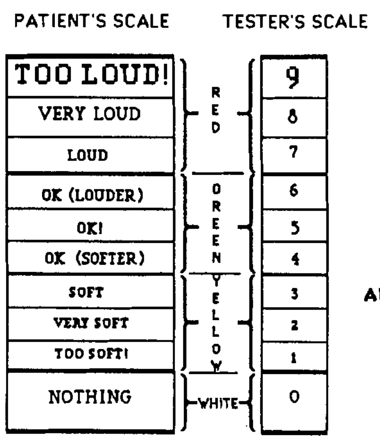

Fig. 1

SCALES USED IN THE MEASUREMENT OF AUDITORY DYNAMIC RANGES

Listeners were instructed to watch the red light and listen carefully only when it was turned on. This visual signal is of importance only at the beginning of each frequency's sequence, when thresholds are being determined. For the clear, suprathreshold signals, the listeners were instructed to decide whether the pulsing tone was louder or softer than the level they would like to hear if they were listening to the tester's voice. If it was softer they were told to push a yellow button. If the next sound was softer they should push a lower yellow button, unless they had already pushed the lowest one in which case they were to push it again. If the tone was "just right", a green button was to be selected. If the next tone was stronger but still "OK", a higher green button could be pushed. If the sound was louder than the desired level, a red button should be selected. When the sound seemed to be so loud that they would not want to hear anything stronger, the "TOO LOUD" button should be selected. At the other end of the scale, if the red light was on but they could not hear any pulsing tone at all, the white "NOTHING" button was depressed. Thresholds were always obtained before the supra-threshold measurements.

A very important part of the procedure is that, after an initial 10 dB-step ascending-level sequence that begins near threshold for each frequency and terminates when the "TOO LOUD" button is chosen, the level is not reduced to a "soft" level but to one which is five decibels above the highest "comfortable" level previously chosen. Several ascending sequences are presented at each frequency, usually starting at progressively higher levels. This procedure forces the "threshold of discomfort" toward higher levels than initially chosen and also expands the range of "comfortable" judgements, thus raising the mean comfort level. The set of sequences for each frequency is terminated when the discomfort judgment is not raised any further.

An individual's MCL is defined as the mid-point between the lowest and the highest "OK" judgement for each frequency, including all ascending sequences. Mean MCL refers to the total group of listeners, when the MCLs for each Hearing Level are averaged. Individual UCLs are the levels at which the "too loud" judgement is repeated. Mean UCL refers to the total group statistic in reference to Hearing Level.

It is important to note that all values shown as greater than 120 dB HL are extrapolated. The extrapolations were based on the judgment made for the highest level heard, or the audiometer's maxima (120 db HL). For instance, if the listener chose a low or mid-comfort button (#4 or #5) for a tone presented at 120 db HL, the discomfort level was assumed to be 140 dB HL or 5 dB for each remaining step in the loudness scale. Since these assumed values depend on the listener's loudness judgement for the audiometer's maximum signal levels they cannot be accepted as firm evidence.

A typical worksheet showing the accumulation of judgements that define an individual's auditory dynamic range is shown in Fig. 2.

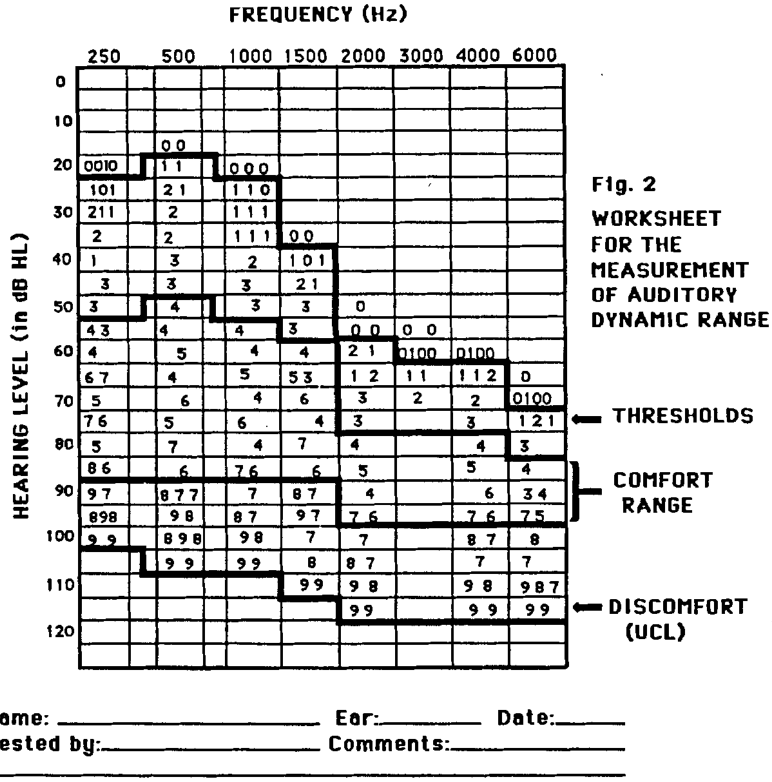

Fig. 2
WORKSHEET FOR THE MEASUREMENT OF AUDITORY DYNAMIC RANGE

RESULTS

1. Following the typical sensorineural loss distribution of Hearing Levels across frequency, the better thresholds appeared more often for the lower frequencies. The various HL data (N) were distributed in the following manner: there were at least 10 thresholds at each 5 dB interval between 0 and 60 dB HL for 500 Hz, between 5 to 65 dB HL for 1000 Hz, between 30 and 80 dB HL for 2000 Hz, and between 40 and 95 dB HL for 4000 Hz. Moreover, there were at least 40 thresholds at each 5 dB interval between 15 and 40 db HL for 500 Hz, between 25 and 55 dB HL for 1000 Hz, between 40 and 60 dB HL for 2000 Hz, and between 45 and 75 dB HL for

4000 Hz. The mean Hearing Levels for these frequencies were: 31.8 dB HL for 500 Hz, 39.4 dB HL for 1000 Hz, 54.1 db HL for 2000 Hz and 67.3 dB HL for 4000 Hz.

2. The distribution of mean MCL and mean UCL judgements across Hearing Levels did not show a significant frequency effect. The means and standard deviations for each frequency are shown in Table 1 for the mean MCLs and in Table 2 for the mean UCLs (included in the Appendix). In Fig. 3, the various means for each frequency are superimposed and compared to the "pooled" mean. Except for those levels in which the number of data points is less than 3, none of the specific frequency curves departed significantly from the "pooled" mean.

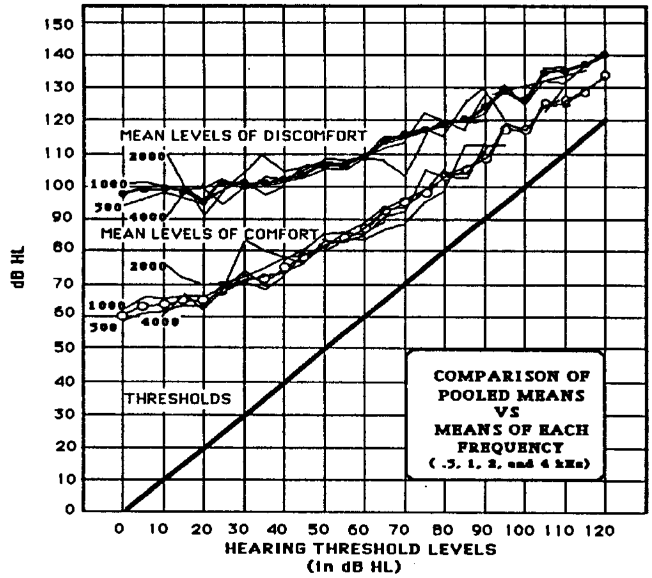

Fig. 3. MEAN COMFORT AND DISCOMFORT LEVELS RE HEARING THRESHOLD LEVELS

3. Since the relation between threshold levels and both MCL and UCL judgements appears to be the same across the four frequencies described, the total number of data points was "pooled". The "pooled" four frequency means for MCL and for UCL, their standard deviations and the corresponding number of data points for each Hearing Level, are described in Tables 3 and 4. For practical purposes, these data can be considered strong for Hearing Levels between 10 and 80 dB HL, where the number of data points (N) is greater than 50; the set is moderately strong between

5 and 90 dB HL, with an N greater than 30. For HTLs above 100 dB HL, with an N smaller than 10, the information may be insufficient.

Figure 4 displays the pooled four-frequency mean MCL and mean UCL in reference to threshold (HTL). The range of plus and minus one Standard Deviation for the above mentioned means is also shown. In general, the slopes of mean MCLs and mean UCLs seem to be different for Hearing Levels within the 0 to 45 dB range than for the 50 to 120 dB range. Mean UCLs stay close to 100 dB HL for thresholds within the 0 to 40 dB HL range. For greater Hearing Levels, the mean UCL increases 5 dB for every 10 dB increase in HL.

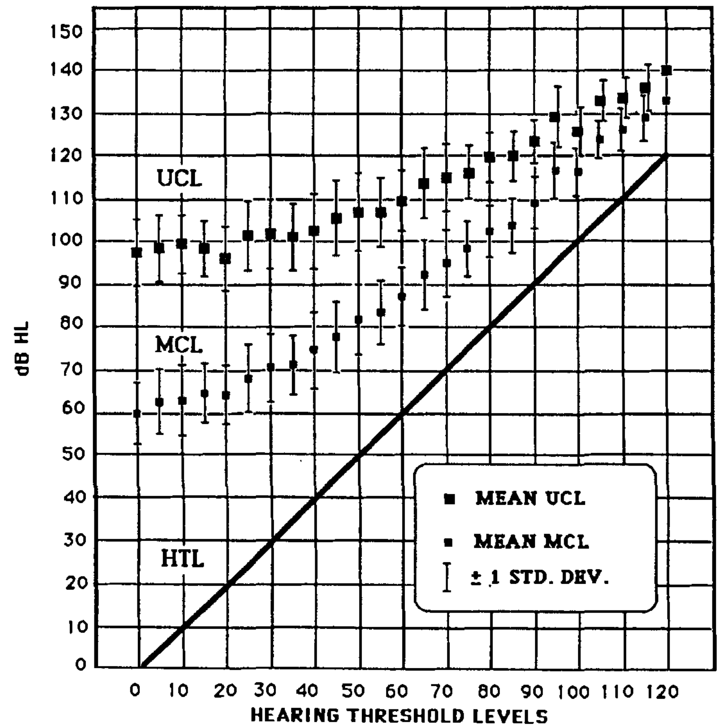

Fig. 4

MEAN COMFORT AND DISCOMFORT LEVELS
RE HEARING THRESHOLD LEVELS

Figure 5 shows a comparison of the present data with similar information compiled by Leeds, in 1983, and quoted by Skinner, 1988. In this unpublished, Master-level independent study, the auditory dynamic ranges of a different group of listeners from the same Clinic (C.I.D.) were tabulated. These 106 listeners were tested with the same procedures and equipment and have a similar age range (51 to 94 years of age). As can be seen, the single frequency mean MCL's of this group are practically the same as those shown in the present study. The mean UCL's are also similar, except for the severe-to-profound loss levels, where the earlier group's mean is higher though still within a + 1 Std. Dev.

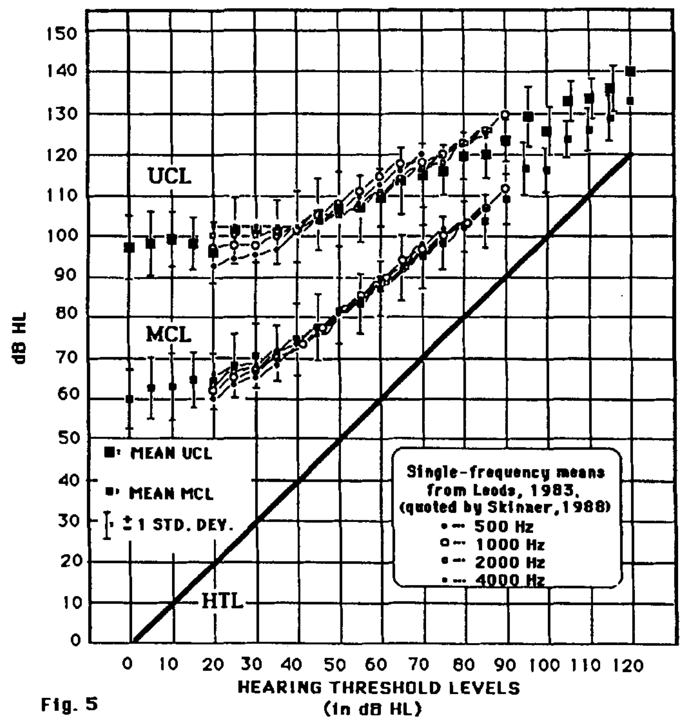

Fig. 5

COMPARISON OF SINGLE-FREQUENCY UCL AND MCL MEANS FROM LEEDS (1983) AND POOLED-MEANS OF THE SAME FREQUENCIES, FROM PASCOE (1988)

Since the ANSI earphone calibration specifications for the audiometers used in these measurements (Grason-Stadler 1701 and GSI-16) show a 10 dB approximate

SPL-to-HL conversion for the frequencies of interest, the UCL judgements stated in dB HL can be estimated in SPL by adding 10 db. Thus, we can say that the normal mean UCL is near 110 db SPL for thresholds between 0 dB and 40 dB HL, while greater Hearing Levels show UCLs that rise 5 dB above that level for every 10 dB HL increase. A formula for predicting the mean UCL (in dB SPL) for thresholds greater than 40 dB HL in this study is:

$$\frac{x \text{ dB HTL} - 40}{2} + 110 \text{ dB SPL} = \text{mean UCL in dB SPL}$$

In comparison, Hawkins, et al (1987) mentioned a formula for the same purpose in which LDL (in dB SPL) is equal to 1/4 the Hearing Level in dB HL plus 100 dB. Their resulting values are in close agreement with ours for Hearing Levels between 20 and 55 db HL, but differ significantly for the severe and profound loss ranges. For instance, from their formula, the predicted mean UCL for an 80 dB HTL is 120 db SPL and for a 100 dB HTL the mean UCL is 125 dB SPL, while in our formula those values would be 130 and 140 dB SPL. These higher SPL values were extrapolated and may be false since it is conceivable that discomfort saturates at levels below 140 dB SPL, where physical discomfort and even pain may be present.

The mean MCLs also show a change of slope in relation to increasing Hearing Levels. From 0 to 45 db HL the slope follows a 1/3 ratio, or a 3.3 db increase in MCL for a 10 dB increase in HTL. For greater HTLs, the slope is closer to 3/4, or an increase of 7.5 dB for every 10 dB increase in HTL.

4. It is important to recognize that, in spite of reasonably strong tendencies for responses that are within plus or minus 10 dB from the means, there is a range that can be as high as 47.5 dB at one Hearing Level, with an average range across the various Hearing Levels of 35 dB both for the MCL and the UCL data. For instance, at 45 dB HL, the minimum MCL was 60 dB HL and the maximum was 107.5 dB HL. At the same threshold level, the minimum UCL was 85 dB HL and the maximum was 125 dB HL. These results are shown in Tables 5 and 6.

COMPARISON OF "GAIN SELECTION" FORMULAS

The differences and similarities among the recommendations derived from various "threshold dependent" formulas have been described previously (Humes, 1986; Byrne, 1987; Skinner, 1988). In general, the findings have been that most formulas achieve the purpose of delivering an audible speech spectrum, and that the over-all level differences among them can be corrected by volume control adjustments.

The auditory dynamic ranges presented in this article can be used to compare several formulas. In order to display the expected speech outputs produced by specific gain recommendations, an assumption must be made in regard to the expected speech input levels. For this purpose, the third-octave band levels described by Pascoe (1978) were used. These levels are the following:

Frequency:	250	500	1000	1500	2000	3000	4000	6000 Hz
Band Level:	40	55	49	50	54	52	52	40 dB HL

The various insertion gains given by each formula can be added to the above speech input levels and the resulting expected speech output levels can be plotted in relation to the mean MCLs. In this manner, at least for hearing aids with linear amplification, the expected amplified speech-band outputs can be evaluated in terms of their audibility and assumed comfort within the listener's auditory dynamic range.

Figure 6 shows the results of applying the half-gain rule to an over-all 55 dB HL speech input level. If this input level is representative of conversational speech, it is evident that the half-gain rule is very efficient in delivering comfortable speech for thresholds within the normal range and up to mild and moderate Hearing Losses (0 to 60 dB HL). This amount of gain appears to be insufficient for the greater losses because the output is below threshold unless, of course, the expected input level is increased.

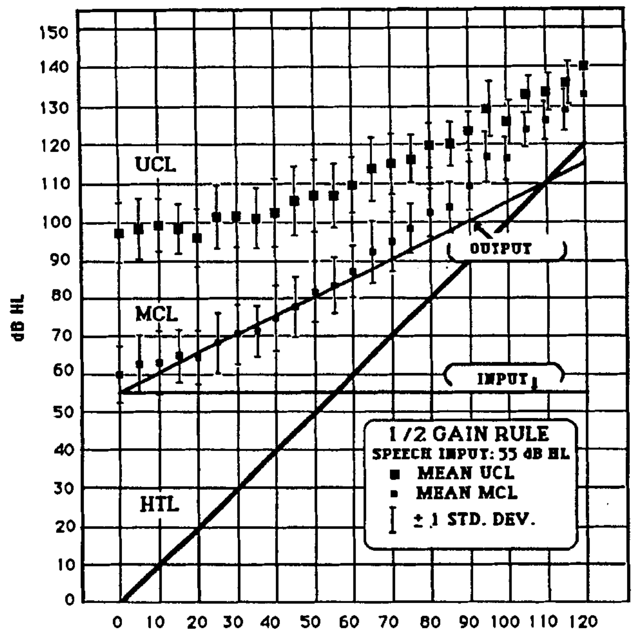

Fig. 6

MEAN COMFORT AND DISCOMFORT LEVELS
RE HEARING THRESHOLD LEVELS

In the next page, Figure 7 displays an application of Dr. Berger's formula. The 500 and 4000 Hz frequencies follow the half-gain formula and show the effects mentioned above. On the other hand, 1000 and 2000 Hz, which receive gains slightly greater than half the loss and as high as 2/3 for 2000 Hz, stay within the plus and minus one Std. Dev. range throughout most of the range of Hearing Levels. However, it can be seen that any ratio that remains constant across Hearing Levels cannot follow the two slopes of MCL, since they change slope at or near the 45 dB HL range.

Figure 8 shows an application of the POGO formula. It can be seen that this formula produces a higher-frequency emphasis than Dr. Berger's and is less efficient for the greater losses. The speech-band outputs are well-placed within the listener's auditory comfort range for the majority of Hearing Levels, at least from normal up to 60 dB HL.

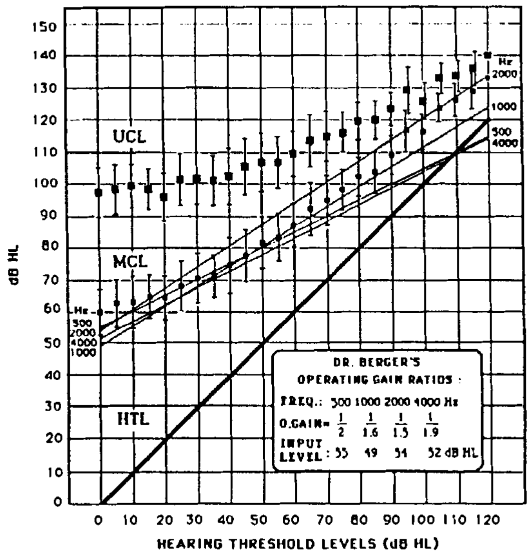

Fig. 7 Speech-band outputs delivered by Dr. Berger's Operating Gains, compared to the mean comfort and discomfort levels

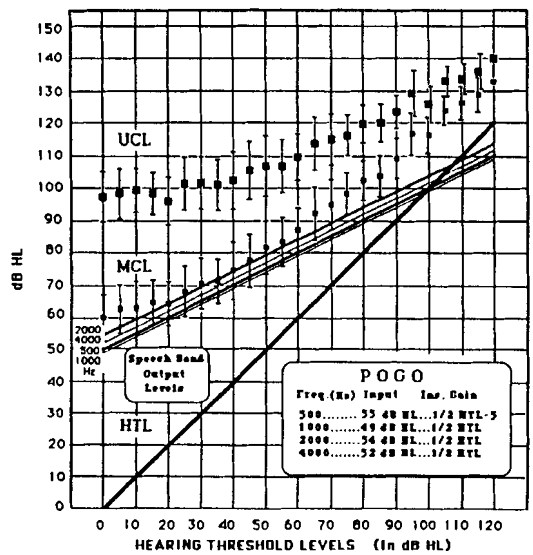

Fig. 8 Speech-outputs delivered by POGO's insertion gains, compared to the mean comfort and discomfort levels.

Figure 9 applies the recent NAL formula (Byrne, D., et al, 1988). This formula uses a gain to HL ratio of 0.46, or slightly less than the "one-half" concept. A different constant value is applied to each frequency, with the lower frequencies receiving a greater reduction than is given by POGO: -17 dB for 250 Hz and -8 dB for 500 Hz in the NAL's formula vs -10 dB and -5 dB for the same frequencies in POGO. Since this formula includes a correction for audiometric slope, the example given here refers only to a "uniform" or flat audiogram. Here again, this formula, applying the input levels selected in this comparison, delivers speech-band outputs within comfort range for thresholds within the mild and moderate hearing losses. The severe and profound losses would not be reached adequately, unless either gain or input levels are raised. It must be remembered however, that the Australian formula is applied to a different speech spectrum, one which appears to have about 5 dB less pressure for the 500 to 2000 Hz range.

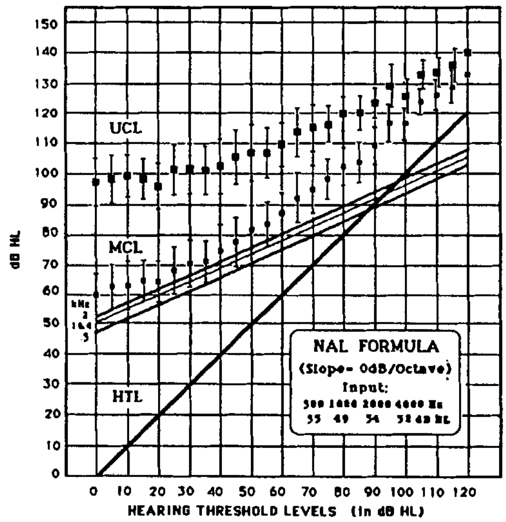

Fig. 9 Speech-band outputs delivered by NAL's formula for a flat audiogram, compared to the mean comfort and discomfort levels.

Figure 10 displays the results of applying the "1/3 to 2/3 rule" suggested by Libby. As can be seen, this concept does include a satisfactory solution for the severe and profound loss levels. The moderate loss range, from this point of view, would be underestimated unless a gradual change from 1/3 to 2/3 ratios in reference to HTL is used. For instance, a 1/2 ratio could be used for the moderate loss range (40 to 60 dB HL).

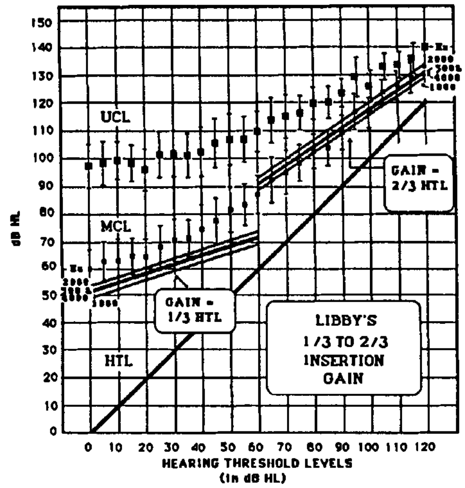

Fig. 10 Speech-band outputs delivered by Libby's suggested 1/3 to 2/3 insertion gains, compared to the mean comfort and discomfort levels.

In Figure 11, a different hypothesis is explored. It has been stated that MCL can be predicted as being at the center of the auditory dynamic range (Wallenfels, 1967). This graph shows that, in spite of being just below all of the measured mean MCLs, this hypothesis is reasonable for HTLs greater than 45 dB HL. For the mild loss range, a +5 to +10 dB correction would be indicated.

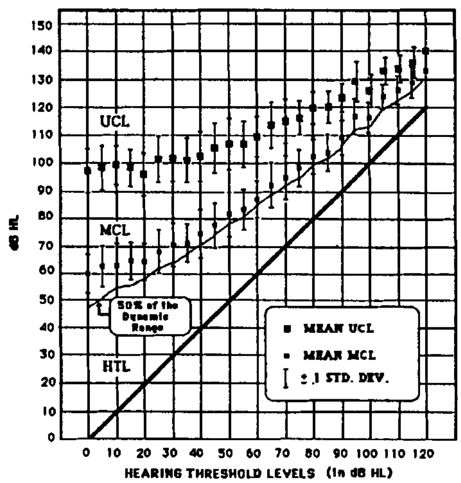

Fig. 11 Comparison of the hypothesis : "MCL = 50% of the Auditory Dynamic Range"

Another way of showing the effects of each formula is to create a reasonable example of an individual's auditory dynamic range and then apply the insertion gains suggested for a chosen audiometric pattern to the previously described average speech spectrum. In this manner, the relation between the expected amplified speech outputs given by one formula and that listener's auditory dynamic range can be compared to the outputs given by other formulas.

In figures 12 to 16, the chosen example is based on the mean Hearing Levels for the population described in this study. Both the MCL and the UCL given are the mean values for the corresponding HTLs. Fig. 12 shows the example's unaided reception of speech, as well as the Articulation Index given in percent, using the Phase IV program described by Popelka and Engebretson (1983). The Articulation Index given is based on the frequency-weighted reception of the average speech band levels, with a range of +12 dB and -18 dB.

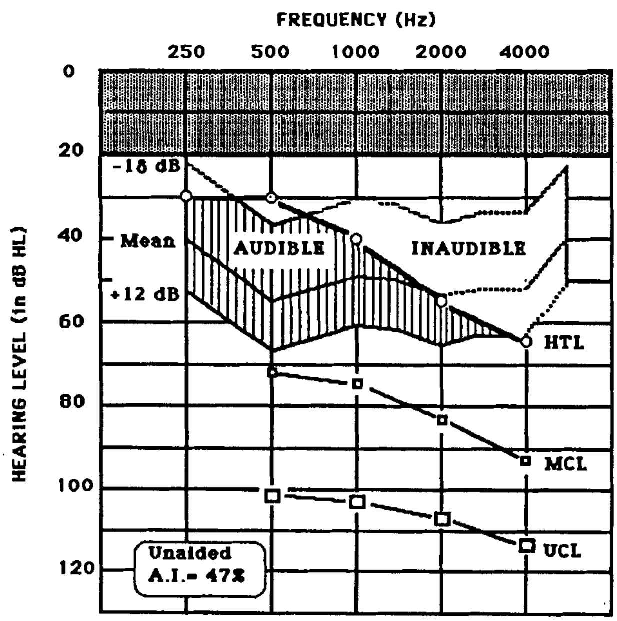

Fig. 12 AVERAGE SPEECH LEVELS AND AUDITORY DYNAMIC RANGE FOR MEAN AUDIOGRAM

In figures 13 to 16, the insertion gains suggested by three formulas are applied to the mean speech band levels shown in fig. 12. Fig. 13 shows the application of Dr. Berger's formula and its resulting aided A.I., which is 97%. Fig. 14 displays the effects of using the POGO formula, which, in spite of recommending slightly less gain, also generates an aided A. I. of 97%. In Fig. 15 the output of the NAL formula is shown, as well as the resulting A.I. of 90%. It is evident that this later formula assumes listener satisfaction with less gain but all three recommendations are well-within each other's range of over-all gain adjustment.

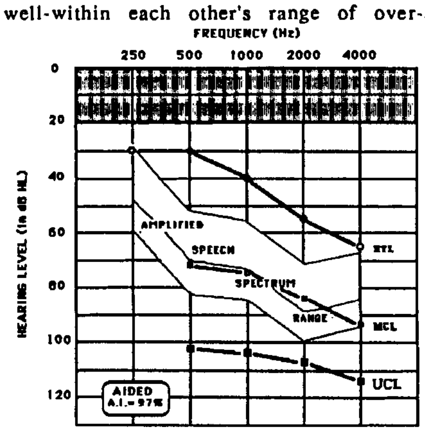

Fig. 13 AUDITORY DYNAMIC RANGE FOR MEAN AUDIOGRAM SPEECH OUTPUT LEVELS FOR DR. BERGER'S FORMULA

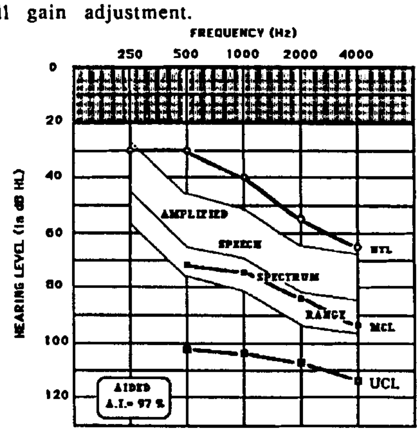

Fig. 14 AUDITORY DYNAMIC RANGE FOR MEAN AUDIOGRAM SPEECH OUTPUT LEVELS FOR POGO'S FORMULA

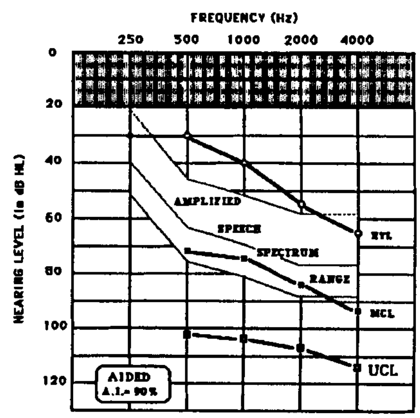

Fig. 15 AUDITORY DYNAMIC RANGE FOR MEAN AUDIOGRAM SPEECH OUTPUT LEVELS FOR NAL'S "FLAT" FORMULA

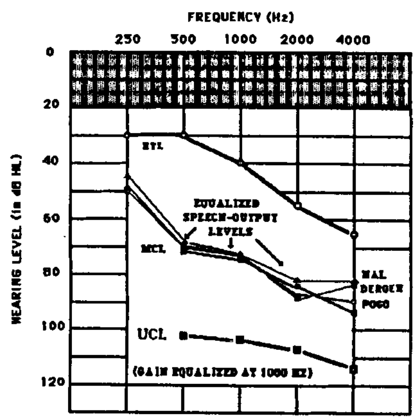

FIG. 16 AUDITORY DYNAMIC RANGE FOR MEAN AUDIOGRAM COMPARISON OF EQUALIZED GAINS FOR THREE FORMULAS

Finally, in fig. 16, the above mentioned formulas are compared by equalizing the gain at 1000 Hz. Their similarity is evident, except at 2000 Hz where the NAL formula provides about 10 dB less emphasis than either the POGO or Berger's formulas. In this frequency these two formulas overshoot the mean MCL, while the Australian formula is just below it. At 4000 Hz, POGO differs from the other two formulas by prescribing more gain. These differences will vary according both to audiometric slope and level, due primarily to the NAL's formula adjustment for slope and to the Berger formula's difference in ratio for the central frequencies.

CONCLUSIONS

1. One inescapable conclusion derived from this set of collected data is that all the formulas for gain selection included in this comparison provide speech outputs that fall within or near the comfort range of the "mean" listener.

2. It can be said that two-thirds of the population included in this study show MCL's that are within plus or minus 7 dB (Average Std. Dev.) of the group's mean MCL.

3. Most MCLs fall 5 to 10 dB above the middle of the auditory dynamic range.

4. However, the total range of possible comfort judgements is sufficiently large to introduce the possibility of significant error, at least for one-third of this population. Individual estimates of either MCL or UCL based entirely on Hearing Threshold Levels can be under or overestimated by as much as 20 dB. This possibility has greater importance for the estimate of UCL, since in most cases this determines the selection of an aid's Maximum Power Output. Over-all gain, on the other hand, is always under the control of the listener.

5. It seems, therefore, that time and effort devoted to the careful exploration of individual auditory dynamic ranges, at least for one or two discrete frequency regions, is warranted. Such efforts can reduce the range of error in the selection of a hearing aid's frequency response.

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APPENDIX, TABLES 1 TO 6

Table 1. Mean MCL, Std. Dev., and N, for four frequencies.
(Mean values are given in dB HTL)

	500 Hz			1000Hz			2000Hz			4000Hz		
HL	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
0	58.9	7.4	14	63.3	6.8	6	-------------			------------		
5	61.0	7.4	22	66.7	6.2	12	-------------			------------		
10	62.5	7.6	39	66.3	9.8	15	77.5	---	1	60.0	---	1
15	64.7	6.9	57	66.7	7.1	32	72.5	---	1	67.5	---	1
20	64.1	7.0	45	66.4	7.6	26	70.0	3.5	2	61.7	7.2	3
25	68.3	7.8	40	69.2	7.9	40	70.5	14.8	5	68.8	5.3	2
30	71.0	7.2	54	71.6	8.4	40	71.4	7.5	11	84.2	14.2	3
35	69.1	7.0	57	73.1	6.2	51	74.8	6.1	24	80.0	---	1
40	72.7	9.0	45	74.0	8.5	63	78.0	6.9	52	77.5	6.7	15
45	78.6	9.1	32	77.0	8.1	63	79.3	9.2	63	80.7	10.0	19
50	80.2	9.6	33	82.8	7.7	47	81.8	7.9	84	84.8	8.4	34
55	83.8	7.7	27	82.8	7.1	44	83.3	7.6	82	84.6	8.4	66
60	83.8	6.5	17	85.1	5.2	26	87.7	6.7	78	88.5	8.2	67
65	87.5	6.1	6	90.7	7.6	22	93.8	8.3	30	92.8	8.7	58
70	88.1	5.2	4	93.2	8.5	7	94.4	8.4	22	96.7	7.7	61
75	96.9	5.9	8	106.3	1.8	2	98.8	8.7	24	98.9	5.9	57
80	99.4	7.7	4	103.3	10.4	3	102.2	5.4	16	103.0	6.4	33
85	112.5	--	1	102.9	4.6	6	103.9	8.6	7	104.5	6.7	22
90	112.5	--	1	113.8	1.8	2	112.5	---	1	108.9	6.6	26
95	112.5	--	1	-------------			-------------			118.9	7.1	10
100	-----------			-------------			-------------			117.3	5.7	16
105	-----------			-------------			123.8	8.8	2 *	124.2	4.1	6 *
110	-----------			125.0	---	1*	129.2	2.9	3 *	124.2	7.6	3 *
115	-----------			-------------			-------------			129.2	5.8	3 *
120	-----------			-------------			-------------			132.5	---	1 *

(* All values greater than 120 dB HL are extrapolated)

Average Standard Deviations (in dB):

	500 Hz	1000Hz	2000Hz	4000Hz
	7.4	6.9	7.6	7.4

Table 2. Mean UCL, Std. Dev., and N, for four frequencies.
(All mean values are given in dB HTL)

	500 Hz			1000 Hz			2000 Hz			4000Hz		
HL	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
0	95.4	9.9	14	101.7	6.8	6	-------------			-------------		
5	97.7	8.7	22	101.3	6.4	12	-------------			-------------		
10	99.1	7.3	39	100.3	6.9	15	110.0	---	1	90.0	---	1
15	97.5	6.8	57	99.1	6.5	32	100.0	---	1	100.0	---	1
20	95.0	7.8	45	100.0	7.1	26	95.0	2.9	2	91.7	2.9	3
25	100.4	8.9	40	102.4	8.5	40	100.0	9.6	5	100.0	0	2
30	102.5	8.4	54	100.8	8.1	40	100.5	9.1	11	106.7	12.6	3
35	97.9	8.7	57	103.3	7.4	51	103.3	7.3	24	110.0	---	1
40	100.2	9.7	45	102.1	9.5	63	104.6	9.0	52	105.0	7.1	15
45	106.6	9.5	32	104.2	8.9	63	105.6	8.9	63	106.3	11.4	19
50	105.3	9.8	33	108.2	9.2	47	107.7	9.1	84	107.8	10.2	34
55	106.7	8.5	27	108.4	7.8	44	107.6	8.3	82	107.8	8.9	66
60	108.2	6.1	17	108.3	6.5	26	110.6	7.1	78	110.3	8.4	67
65	108.3	7.5	6	112.9	6.8	22	115.2	8.0	30	113.9	9.3	58
70	103.8	4.8	4	114.3	6.7	7	115.5	8.4	22	115.4	7.7	61
75	116.3	6.4	8	122.5	10.6	2	116.9	7.2	24	116.6	5.7	57
80	115.0	5.8	4	120.0	10.0	3	119.7	4.6	16	120.5	6.0	33
85	125.0	---	1*	117.5	4.2	6	120.7	6.7	7	120.2	6.5	22
90	130.0	---	1	127.5	3.5	2	120.0	---	1	123.3	5.6	26
95	120.0	---	1	-------------			-------------			130.5	7.2	10
100	-------------			-------------			-------------			126.6	6.3	16
105	-------------			-------------			135.0	7.1	2	132.5	4.2	6
110	-------------			135.0	---	1	136.7	2.9	3	131.7	7.6	3
115	-------------			-------------			-------------			136.7	5.8	3
120	-------------			-------------			-------------			140.0	---	1

* All values greater than 120 dB HL are extrapolated.

Average Standard Deviations (in dB):

	500 Hz	1000 Hz	2000 Hz	4000Hz
	7.9	7.4	7.3	7.0

Table 3. Mean MCL, Std. Dev. and N, for HLs 0 to 120 dB
Pooled data for 500 to 4000 Hz.
(All mean values are in dB HTL)

HL	Mean	S. D.	N
0	60.25	7.39	20
5	63.02	7.43	34
10	63.75	8.45	56
15	65.55	6.96	91
20	64.93	7.19	76
25	68.85	8.18	87
30	71.64	8.07	108
35	71.77	6.90	133
40	75.16	8.31	175
45	78.50	8.91	177
50	82.30	8.32	198
55	83.66	7.76	219
60	87.27	7.19	188
65	92.37	8.33	116
70	95.53	7.99	94
75	98.85	6.75	91
80	102.55	6.33	56
85	104.38	6.69	36
90	109.50	6.31	30
95	117.50	6.89	11
100	117.34	5.74	16
105	124.06	4.81	8
110	126.43	5.37	7
115	129.17	5.77	3
120	132.50	--	1

(Average Std. Dev. = 7.17 dB)

Table 4. Mean UCL, Std. Dev. and N, for HLs 0 to 120 dB
Pooled data for 500 to 4000 Hz.
(All mean values are dB HTL)

HL	Mean	S. D.	N
0	97.25	8.39	20
5	98.97	8.05	34
10	99.46	7.30	56
15	98.08	6.66	91
20	96.58	7.71	76
25	101.26	8.60	87
30	101.76	8.44	108
35	101.05	8.35	133
40	102.63	9.33	175
45	105.37	9.25	177
50	107.45	9.44	198
55	107.69	8.38	219
60	109.97	7.47	188
65	113.75	8.52	116
70	114.84	7.95	94
75	116.76	6.21	91
80	119.82	5.88	56
85	120.00	6.09	36
90	123.67	5.56	30
95	129.55	7.57	11
100	126.56	6.25	16
105	133.13	4.58	8
110	134.29	5.35	7
115	136.67	5.77	3
120	140.00	--	1

(Average Std. Dev. = 7.38 dB)

Table 5. Range of Mean MCL
Pooled data for four
frequencies: 500 to 4000 Hz
(Min. and Max. values are dB HTL)

HL	Min	Max	Range
0	42.5	75.0	32.5
5	52.5	80.0	27.5
10	45.0	82.5	37.5
15	55.0	90.0	35.0
20	50.0	87.5	37.5
25	50.0	95.0	45.0
30	57.5	100.0	42.5
35	55.0	90.0	35.0
40	52.5	100.0	47.5
45	60.0	107.5	47.5
50	65.0	102.5	37.5
55	67.5	107.5	40.0
60	72.5	112.5	40.0
65	77.5	115.0	37.5
70	82.5	117.5	35.0
75	85.0	115.0	30.0
80	87.5	117.5	30.0
85	95.0	117.5	22.5
90	97.5	120.0	22.5
95	107.5	130.0	22.5
100	107.5	127.5	20.0
105	117.5	130.0	12.5
110	117.5	132.5	15.0
115	122.5	132.5	10.0
120	132.5	132.5	-----

Total average range = 31.8
Av. Range for 0 to 90 dB HL
(N > than 20) = 35.9

Table 6. Range of Mean UCL
Pooled data for four
frequencies: 500 to 4000 Hz
(Min. and Max. values are dB HTL)

HL	Min	Max	Range
0	70.0	110.0	40.0
5	80.0	110.0	30.0
10	80.0	110.0	30.0
15	80.0	115.0	35.0
20	80.0	115.0	35.0
25	80.0	115.0	35.0
30	85.0	120.0	35.0
35	80.0	120.0	40.0
40	85.0	125.0	40.0
45	85.0	125.0	40.0
50	85.0	130.0	45.0
55	90.0	130.0	40.0
60	90.0	130.0	40.0
65	95.0	130.0	35.0
70	95.0	135.0	40.0
75	100.0	130.0	30.0
80	100.0	130.0	30.0
85	110.0	130.0	20.0
90	115.0	130.0	15.0
95	120.0	145.0	25.0
100	115.0	135.0	20.0
105	125.0	140.0	15.0
110	125.0	140.0	15.0
115	130.0	140.0	10.0
120	140.0	140.0	----

Total average range = 30.8
Average range for 0 to 90 dB HL
(N > than 20) = 34.5

DISCUSSION

Dreschler: Is it correct to describe a patient's hearing with an articulation index which is essentially a signal property and not a patient property ?

Pascoe: That is right but we find it valuable in terms of evaluating amplification.
A person could conceivably have an articulation index of 100 % and understand nothing, it is not correlated with discrimination scores for impaired subjects. There is a high correlation for normal listeners and even mild hearing losses. There is a higher probability of discriminating when you have a higher articulation index in general but there is not a one to one correspondance.

Poulsen: On your worksheet there was an indication of the comfort range. It seems to be rather wide at low frequencies and rather narrow at high frequencies. Is it a matter of reduced dynamic range at high frequencies ?

Pascoe: The higher frequencies have elevated hearing threshold. It is a hearing level related reduction in the range.