Selecting and Verifying Hearing Aid Performance Characteristics for Young Children

Richard C. Seewald
University of Western Ontario

Mark Ross
University of Connecticut

Patricia G. Stelmachowicz
Boys Town National Institute for Communication Disorders in Children

A primary goal of hearing aid fittings with young children is to provide an amplified speech signal which is audible, comfortable, and undistorted across the broadest relevant frequency range possible. Selection and verification methods which focus on aided detection thresholds do not relate performance to expected speech input levels. A procedure is described which includes: (a) prescribing the desired sensation level of amplified speech in specific frequency regions, (b) calculating the level to which speech must be amplified to achieve the desired sensation levels above a given threshold curve, (c) calculating the desired gain by comparing the target speech levels to average conversational speech levels, (d) verifying that speech has been optimally amplified through in-situ measures with a speech-shaped input signal approximating the overall level of average conversational speech, and (e) verifying that appropriate output limiting levels have been achieved using in-situ measures.

The task of providing hearing-impaired children with suitable amplification is an audiological problem which can challenge even the most experienced and skillful clinician. Unquestionably there remains a need for systematic investigation and thoughtfulness as we have yet to reach consensus regarding many aspects of this problem. This report will focus particular attention on is-

Richard C. Seewald, PhD, is an Assistant Professor of Audiology, Department of Communicative Disorders, Elborn College, University of Western Ontario, London, Ontario, N6G 1H1. Mark Ross, PhD, is a Professor of Audiology, Department of Communication Sciences, University of Connecticut, U-85, Storrs, Connecticut, 06268. Patricia G. Stelmachowicz, PhD, is Coordinator, Audiological Services, Boys Town National Institute for Communication Disorders in Children, Omaha, Nebraska, 68131.

sues related to the electroacoustic selection and verification of real-ear hearing aid performance characteristics with children. The supra-threshold orientation to selection and verification which is outlined evolves from a general goal to provide an amplified speech signal which is audible, comfortable, and undistorted across the broadest relevant frequency range possible.

Our present position related to the selection of frequency-gain characteristics for children is that one must first decide what relationship the amplified speech spectrum is to have relative to a given child's detection thresholds. It is only then that one can specify the specific frequency-gain characteristics which will be required to accomplish this. By approaching the problem of selection in this way, the gain which the hearing aid provides as a function of frequency is viewed more as a by-product of the selection process rather than a goal in and of itself.

Current gain-by-frequency formulas (Berger, 1976; Byrne & Dillon, 1986; McCandless & Lyregaard, 1983) have been derived from the average gain used by samples of adventitiously hearing-impaired adults with mild to moderately-severe hearing loss. Despite their availability as software options with commercially available probe-tube microphone systems, their appropriateness with children, particularly those with severe to profound hearing loss, remains open to question.

The approach to be described has grown out of some excellent work done with children at the Central Institute for the Deaf during the early 1970s. This work was first reported in the seminal article by Gengel, Pascoe, and Shore (1971) and subsequently elaborated upon by Erber (1973). A primary objective of their supra-threshold speech spectrum based procedure was to select a hearing aid which amplified and made audible as much of the speech spectrum as possible within the given limitations of the child's residual hearing characteristics. With this objective, a real-ear verification procedure was developed which assessed the sensation level of noise band stimuli presented at average conversational speech levels. They reported that this allowed them to assess the extent to which a given hearing aid accomplished their goal of delivering the broadest spectrum of sound at at least 10-20 dB above threshold. Gengel and his co-workers proposed that such a procedure insured that speech would be audible to the child and that the levels associated with amplified speech would not be so high as to cause discomfort.

THE DSL (DESIRED SENSATION LEVEL) SELECTION METHOD

The specific details of our electroacoustic selection method for children have been presented in Seewald, Ross, and Spiro (1985) and more recently in Seewald and Ross (1988). As shown in Figure 1, we have developed estimates of desired sensation levels (DSLs) for amplified speech which vary as a function of both hearing level and frequency region (Seewald & Ross, 1988). If one is willing to accept these DSLs as at least a reasonable starting place in electroacoustic selection, then all that is required is to determine the gain within each frequency region which is required to amplify the average long-term speech spectrum (LTSS) to the desired levels. In addition to frequency-gain characteristics, the selection model projects desired maximum real-ear sound pressure levels (SPLs) at which the hearing aid output should be limited as a function of frequency.

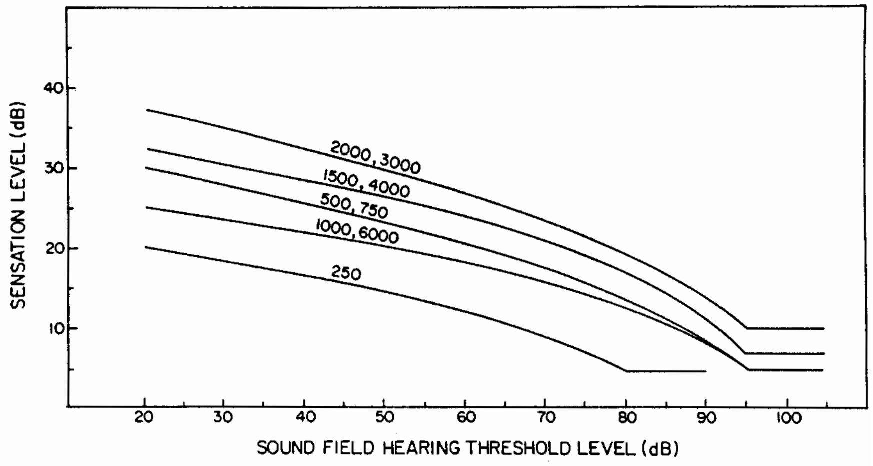

Figure 1. The desired sensation levels for the long-term average speech spectrum as a function of sound field hearing threshold level and frequency region. (From "Amplification for Young Hearing-Impaired Children" by R. Seewald and M. Ross, 1988, in *Amplification for the Hearing-Impaired* (p. 234) edited by M. Pollack, Orlando, FL: Grune & Stratton. Copyright 1988 by Grune & Stratton. Reprinted by permission.)

By way of illustration, Figure 2 presents the unaided sound field thresholds (S) in dB SPL for a child with a moderately-severe sensorineural hearing loss. Also included in this figure are the normal monaural minimal audible field (MAF) thresholds reported by Morgan, Dirks, and Bower (1979), the LTSS (shaded area; Cox, 1983), the target SPLs for amplified speech, and the desired maximum real-ear SPLs we project as appropriate for this child.

Table 1 illustrates how the desired real-ear gain is calculated for the situation presented in Figure 2. First, the desired sensation levels are determined from the curves presented in Figure 1 using the child's unaided sound field thresholds in dB HL. As shown in Table 1, the desired sensation levels (line 2) are added to the child's detection thresholds in dB SPL (line 3) within each frequency region. The result (line 4) provides the target levels in dB SPL for the amplified speech spectrum. The desired real-ear gain (line 6) is determined as a function of frequency by simply calculating the difference between the target levels for amplified speech (line 4) and the unamplified long-term aver-

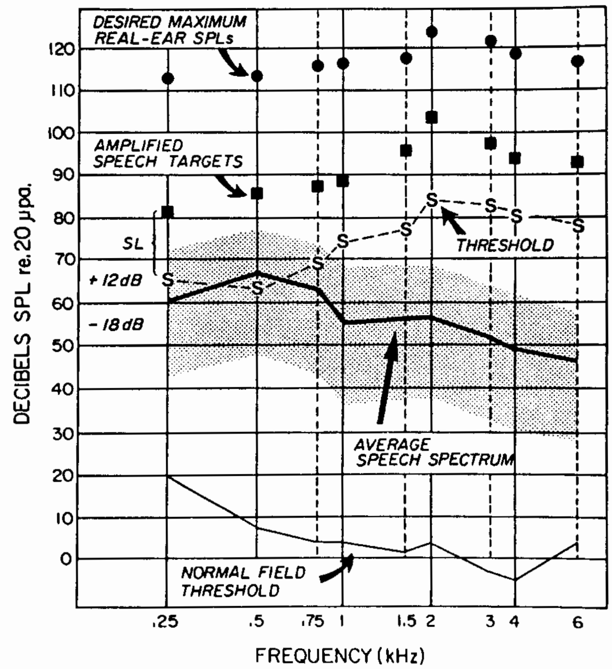

Figure 2. Unaided sound field audiogram in dB SPL (S) for a child with a moderately-severe sensorineural hearing loss. The target sound pressure levels for amplified speech (■) and desired maximum sound pressure levels (•) are shown as a function of frequency. The long-term average speech spectrum (adapted from Cox, 1983) with its associated 30-dB intensity range is also shown.

age speech spectrum (line 5). If the child can be provided with an amplification system which delivers real-ear characteristics as specified by our selection model, the end result in terms of the amplified spectrum and output limiting would be that as illustrated in Figure 3.

The advantage of the DSL approach can be seen in contrast to the results of a typical gain-by-frequency approach. Byrne and Dillon (1986, p. 264) of the National Acoustic Laboratories (NAL) in Australia described some of the limitations of the Revised NAL gain-by-frequency formulas. Specifically they observed that, when the half-gain rule or one of its variations is used in prescribing the frequency-gain characteristics for the severely impaired, much of the amplified speech spectrum is essentially inaudible. To illustrate, we have computed the projected sensation levels of amplified speech for the child whose detection thresholds are shown in Figures 2 and 3. These projections were developed with two different sets of frequency-gain characteristics including: (a) those prescribed by the Revised NAL system (Byrne & Dillon, 1986) and (b) those resulting from the desired sensation level approach (Seewald & Ross, 1988).

Table 1
Illustration of How Desired Real-Ear Gain is Calculated

	Frequency (kHz) .25	.5	.75	1	1.5	2	3	4	6
Thresholds (dB HL)	45	55	65	70	75	80	85	85	75
Desired Sensation Levels (dB)	16	22	19	15	18	19	16	14	13
Thresholds (dB SPL) (+)	65	63	69	74	78	84	82	80	79
Amplified Speech Targets (dB SPL)	81	85	88	89	96	103	98	94	92
Speech Spectrum (dB SPL) (-)	60	66	62	55	57	57	51	49	47
Desired Real-Ear Gain (dB)	21	19	26	34	39	46	47	45	45

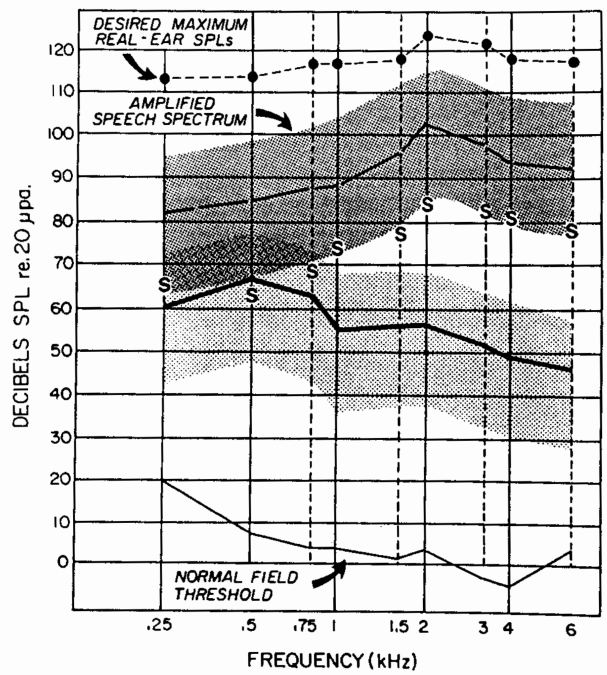

Figure 3. Unaided sound field audiogram in dB SPL (S) and the hypothetical result of hearing aid fitting using the DSL procedure (see text).

The theoretical outcome associated with these two selection strategies is illustrated in Figure 4. It can be observed that the DSL approach provides an amplified speech spectrum which is audible across the entire frequency range with sensation levels at individual frequencies ranging from 13 to 22 dB. For this example the average SL of the LTSS is 16.8 dB across frequency with the DSL approach. In contrast, the SLs of amplified speech resulting from the Revised NAL prescription range from - 1 to 22 dB with an average SL of 9.2 dB across frequency.

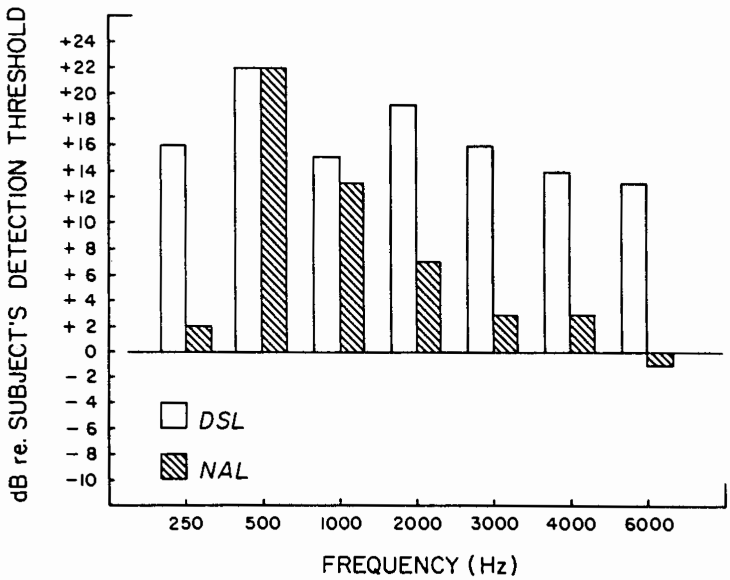

Figure 4. Projected levels of the amplified speech spectrum (dB) relative to unaided detection thresholds for the case example using the Revised NAL (Byrne & Dillon, 1986) and DSL (Seewald & Ross, 1988) selection strategies.

This example should serve to illustrate one relative advantage of using a supra-threshold approach in selecting the frequency-gain characteristics for children with severe to profound hearing loss. If electroacoustic selection is based strictly on the Revised NAL or other threshold-based formula in combination with a probe-tube microphone measurement of insertion gain, the clinician might verify delivery of the prescribed frequency-gain characteristics but fail to provide some children with an amplified speech signal which is sufficiently above threshold across frequency.

VERIFICATION

Having developed some working estimates of appropriate electroacoustic characteristics for a given child, the clinician then chooses a hearing aid and earmold coupling system which should approximate the selection criteria in terms of real-ear performance. At this point, a real-ear measurement of hearing aid performance is made and the extent to which the desired characteristics have been achieved is verified.

Gengel et al. (1971) and Erber (1973) have described procedures for verifying hearing aid performance characteristics with children, but they have not attracted particular attention with the exception of one study reported by Schwartz and Larson (1977). In this study, three hearing aid evaluation procedures were compared including (a) the conventional unaided versus aided sound field audiogram, (b) the sensation level procedure developed by Gengel at al. (1971), and (c) the Erber (1973) modification of the sensation level approach which included use of the child's own earmold attached to a hearing aid receiver for stimulus presentation. Of particular importance was the finding that, for one severely to profoundly hearing-impaired child, the conventional aided versus unaided threshold comparison over-estimated the usefulness of amplification at conversational speech input levels. In contrast, the two sensation level procedures indicated that, of the hearing aids evaluated, none would have provided an amplified speech signal above the child's threshold of hearing. Thus Schwartz and Larson (1977, p. 406) concluded that the conventional sound field audiogram approach to assessing real-ear hearing aid performance was "... inappropriate for determining usable amplification for severe to profoundly impaired children," and advocated the use of a speech spectrum based sensation level procedure which more adequately predicts the audibility of amplified speech for the individual child.

For a variety of reasons, we are now using probe-tube microphone measurements of the in-situ response in dB SPL as the primary verification method. With this direct measurement of hearing aid performance, the critical relationships among the child's detection thresholds, the amplified speech spectrum, and the output limiting characteristics of the hearing aid can be more easily studied.

Unfortunately such direct comparisons are not possible by means of the aided audiogram. To illustrate, Figure 5 presents both aided and unaided thresholds in dB HL for our case example. At first glance, this might be viewed as a generally successful hearing aid fitting. Without careful study of the relationship between the projected amplified speech spectrum and the output limiting characteristics of the hearing aid, however, it is not possible to know how much of the measured functional gain would be available when the input signal is conversational speech rather than relatively low level narrow band or warble tone audiometric stimuli.

To develop this point further we have: (a) calculated the amount of functional gain by frequency from the aided-to-unaided threshold differences shown in Figure 5, (b) calculated the hearing aid's projected output in dB SPL for a speech input signal (average LTSS values + functional gain), and (c) established an output limiting level of approximately 110-115 dB SPL. The

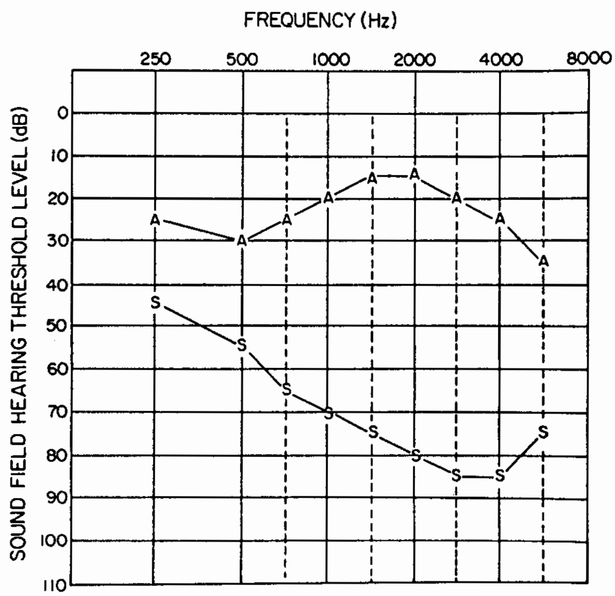

Figure 5. A conventional aided (A) and unaided (S) sound field audiogram in dB HL for a child with a moderately-severe sensorineural hearing loss.

outcome is illustrated in Figure 6. By viewing the relevant aspects of this fitting in this manner, one can observe the effect of the output limiting on the amplified speech spectrum. Although the aided versus unaided detection threshold comparison indicates a real-ear (functional) gain of 65 dB at 2000 Hz for example, this amount of gain would be unavailable with a one-third octave band level input of 57 dB within this frequency region because of the output limiting level of 115 dB SPL. The open area above the output limiting level reflects the extent to which the real-ear gain provided by the hearing aid needs to be reduced, assuming that output limiting levels are to be held constant and saturation of the amplified speech spectrum is to be avoided. The situation presented in Figure 6 provides an explanation for Schwartz and Larson's (1977) finding that the aided sound field audiogram can overestimate the usefulness of amplification at conversational speech input levels for severely to profoundly hearing-impaired children.

The case example will be used in the following to illustrate application of the in-situ response verification procedure in combination with the DSL selection strategy. As noted earlier, the target SPLs for amplified speech result from the selection process (see Figure 2). The target SPLs for amplified speech for the case example are presented in Figures 7 and 8 along with the in-situ response curves. The curves presented in both figures were obtained using a probe-tube microphone system (Fonix 6500) while driving the same hearing

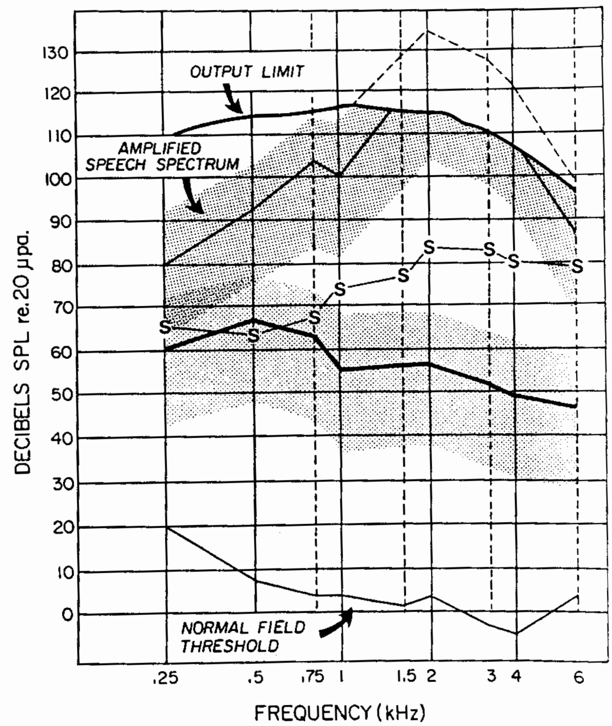

Figure 6. Unaided sound field audiogram in dB SPL (S) and the hypothetical result of amplifying the long-term speech spectrum with the frequency-gain characteristics reflected by the functional gain by frequency shown in Figure 5 and with an output limiting level of approximately 110-115 dB across frequency.

aid with a speech-weighted composite noise (Fry, 1986) having an overall RMS amplitude of 70 dB SPL.

The in-situ response curve shown in Figure 7 was obtained with all controls of the child's hearing aid adjusted to their previously recommended settings. This fitting had been performed at another audiological setting and therefore the actual electroacoustic selection method used was unknown. When the in-situ response curve shown in Figure 7 is compared to the target SPLs for amplified speech, generally good agreement is observed within the mid-frequency range (750-2000 Hz). For the frequency regions above and below this range however, the in-situ response curve departs markedly from the target levels, indicating insufficient SLs for amplified speech.

The in-situ response curve shown in Figure 8 was obtained with the same hearing aid and under the same measurement conditions. Prior to this measurement however, both the volume and tone controls were readjusted along with the addition of an acoustically-tuned ear hook. Although some discrepancy between the in-situ response and target SPLs for amplified speech can be

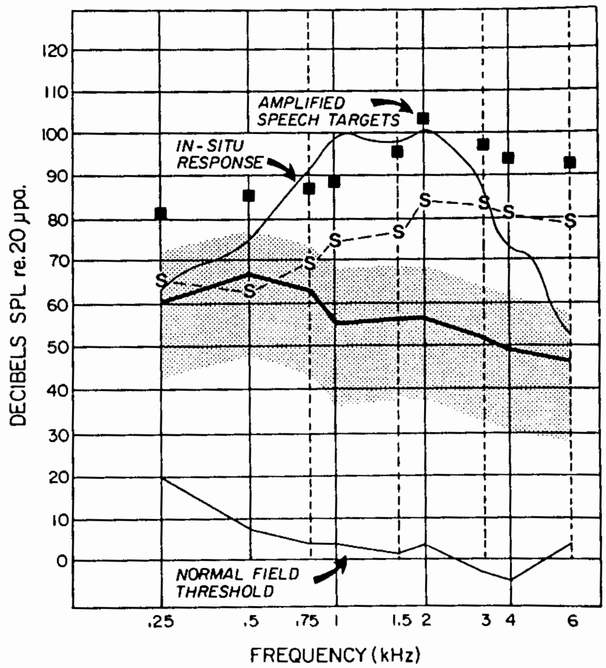

Figure 7. The in-situ response of a child's hearing aid in dB SPL relative to the target amplified speech levels (■) and the child's unaided sound field thresholds (S).

observed, with relatively minor adjustment the response of this hearing aid has been brought more closely in line with the desired specifications.

As noted earlier, the electroacoustic selection model projects maximum SPL values at which hearing aid output should be limited as a function of frequency. The desired maximum SPL values for the case example are plotted in Figures 9 and 10 along with the in-situ response curves obtained with 90 dB SPL pure tones. The in-situ response curve shown in Figure 9 was obtained with all controls of the child's hearing aid adjusted to their previously recommended settings. Generally poor agreement can be observed between the desired maximum levels and the real-ear levels within most frequency regions. At 250 Hz for example, the real-ear output falls nearly 30 dB below the desired level. With the hearing aid adjusted in this way it is likely that the amplifier will saturate immediately with an average conversational speech input signal. Additionally, it can be observed that the unnecessarily high real-ear SPL of 136 dB at 2000 Hz exceeds the desired maximum level by 14 dB.

The in-situ response curve shown in Figure 10 was obtained under the same measurement conditions as that shown in Figure 9 except for the volume control, tone control, and ear hook modifications referred to within the previous section. It can be seen that these relatively simple modifications resulted

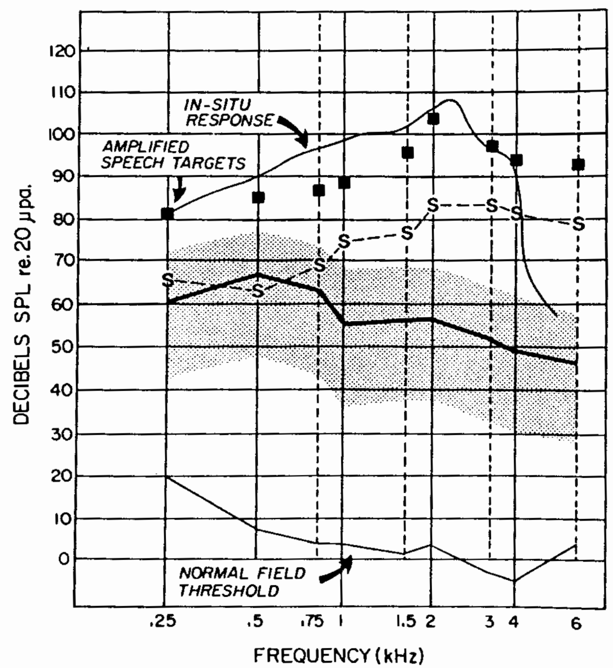

Figure 8. The in-situ response in dB SPL of the same hearing aid as shown in Figure 7 after modifications to more closely approximate the DSL selection criteria (see text). S=the unaided sound field thresholds.

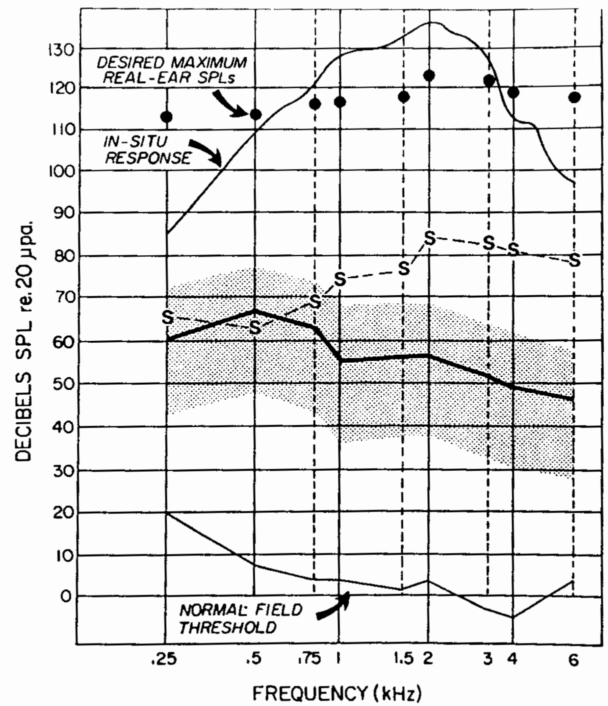

Figure 9. The in-situ saturation sound pressure levels of the child's hearing aid relative to the desired maximum real-ear SPLs (•) prescribed by the DSL approach (Seewald & Ross, 1988) and the child's unaided sound field detection thresholds (S).

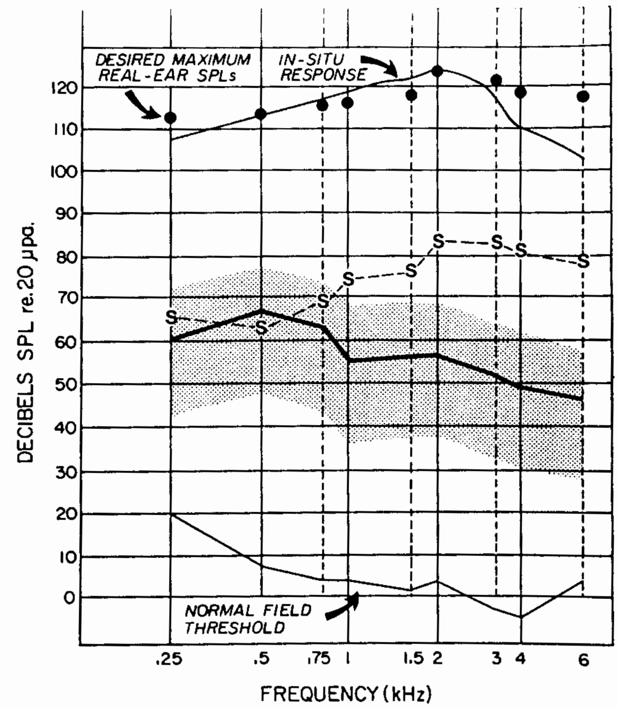

Figure 10. The in-situ SSPL response of the same hearing aid as shown in Figure 9 after modifications to more closely approximate the DSL selection criteria (see text). S = the unaided sound field thresholds.

in an in-situ reponse which more closely approximates the selection criteria for output limiting.

This case example should serve to illustrate the usefulness of the in-situ response as a way of measuring certain aspects of real-ear hearing aid performance which, prior to the availability of probe-tube microphone systems, could only be inferred. It needs to be recognized however that the usefulness of this measurement will depend upon the validity of the electroacoustic selection strategy employed as well as the precision with which the measurement is made. Substantial research with children is needed in both areas. Finally it must be acknowledged that probe-tube microphone measurements provide the means for assessing real-ear *electroacoustic* performance and not *auditory* performance. There is a continuing need to develop more valid and reliable instruments for quantifying the outcome of our hearing aid fittings with children within the area of auditory performance.

ACKNOWLEDGEMENT

We gratefully acknowledge the contributions of David B. Hawkins and J.P. Gagné to this work.

REFERENCES

Berger, K. (1976). Prescription of hearing aids: A rationale. *Journal of the American Audiological Society, 2,* 71-78.

Byrne, D., & Dillon, H. (1986). The National Acoustic Laboratories' new procedure for selecting the gain and frequency response of a hearing aid. *Ear and Hearing, 7,* 257-265.

Cox, R. (1983). Using ULCL measures to find frequency/gain and SSPL90. *Hearing Instruments, 34*(7), 17-21, 39.

Erber, N. (1973). Body-baffle effects and real-ear effects in the selection of hearing aids for deaf children. *Journal of Speech and Hearing Disorders, 38,* 224-231.

Fry, G. (1986). High-speed real-time hearing aid analysis. *The Hearing Journal, 39,* 21-26.

Gengel, R., Pascoe, D., & Shore, I. (1971). A frequency-response procedure for evaluating and selecting hearing aids for severely hearing impaired children. *Journal of Speech and Hearing Disorders, 36,* 341-353.

McCandless, G., & Lyregaard, P. (1983). Prescription of gain/output (POGO) for hearing aids. *Hearing Instruments, 34*(1), 16-21.

Morgan, D., Dirks, D., & Bower, D. (1979). Suggested threshold sound pressure levels for frequency modulated (warble) tones in the sound field. *Journal of Speech and Hearing Disorders, 44,* 37-54.

Schwartz, D., & Larson, V. (1977). A comparison of three hearing aid evaluation procedures for young children. *Archives of Otolaryngology, 103,* 401-406.

Seewald, R., & Ross, M. (1988). Amplification for young hearing-impaired children. In M. Pollack (Ed.), *Amplification for the hearing-impaired* (3rd ed., pp. 213-271). Orlando, FL: Grune & Stratton.

Seewald, R., Ross, M., & Spiro, M. (1985). Selecting amplification characteristics for young hearing-impaired children. *Ear and Hearing, 6*(1), 48-53.