Modification of Hearing Aid Frequency Response

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"Selective amplification" has been defined as the choice of a hearing aid whose gain vs. frequency characteristics form a mirror image of the patient's pure tone audiogram. Early research did not confirm the utility of the concept. Subsequently, extension and popularization of knowledge about real ear vs. artificial ear (2 cm^3 coupler) differences revealed errors in estimated frequency response in selective amplification studies. Finally, improvements occurred regarding: (a) known effect of earmold variations, and (b) flexibility in electronic control of frequency response. These factors supported by clinical examples suggest the validity of the selective amplification concept.

There are differences of opinion regarding the best procedure for evaluation and selection of hearing aids. Regardless of individual philosophy regarding hearing aid evaluation, however, criteria are needed for selecting the hearing aid's frequency response and evaluating the results of the selection. Early efforts to select an appropriate frequency response involved the concept of "selective amplification", for which there were two basic premises: (a) the hearing aid should have as much gain as the degree of hearing loss, and (b) the frequency response of the aid should be a "mirror image" of the patient's audiogram.

Observation of patient behavior indicated that the first premise, aided thresholds "corrected" to 0 dB HL, resulted in overamplification and tolerance problems. To evaluate the second premise, the "Harvard Report" included an extensive study of the effects of frequency response on speech discrimination (Davis, Stevens, Nichols, Hudgins, Marquis, Peterson, & Ross, 1947). The findings suggested that there was no close relationship between a frequency response which reflected the audiometric contour and improved speech intelligibility. The study investigated a number of response configuarations and concluded that hearing-impaired listeners experienced best speech discrimination with an amplification contour that was flat or which rose at the rate of 6 dB/octave. The implication followed that it was not important to select a frequency response which matched the patient's

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audiogram. Subsequently, the concept of selective amplification became unpopular, although it is suspected that clinicians continued to use frequency contour as an initial criterion in pre-selection of hearing aids. Aided discrete frequency test results were often not obtained or considered in the final hearing aid selection, with audibility and discrimination of speech becoming the determining criteria.

Three factors associated with the above misconceptions probably led to erroneous conclusions regarding the usefulness of selective amplification. The first relates to observations that efforts to provide as much gain as the degree of loss at a given frequency resulted in subjective reports of overamplification. Second, attempts to achieve a frequency response which constituted a mirror image of the audiogram utilized 2 cm^3 coupler data and did not consider either coupler/ real ear differences or the modifications of ear canal resonance by an occluding earmold during hearing aid use. Commenting on the coupler error, Lybarger (1978) estimated the real ear correlate of the Harvard Report's "flat" and "6 dB/ octave rising" frequency responses to be as shown in Figure 1. Inspection of this figure reveals that the "flat" curve actually falls at the rate of about 4 dB/ octave for progressively higher frequencies. The "6 dB/ octave rising" curve in reality rises 9 dB/ octave to about 1000 Hz, above which it is essentially flat.

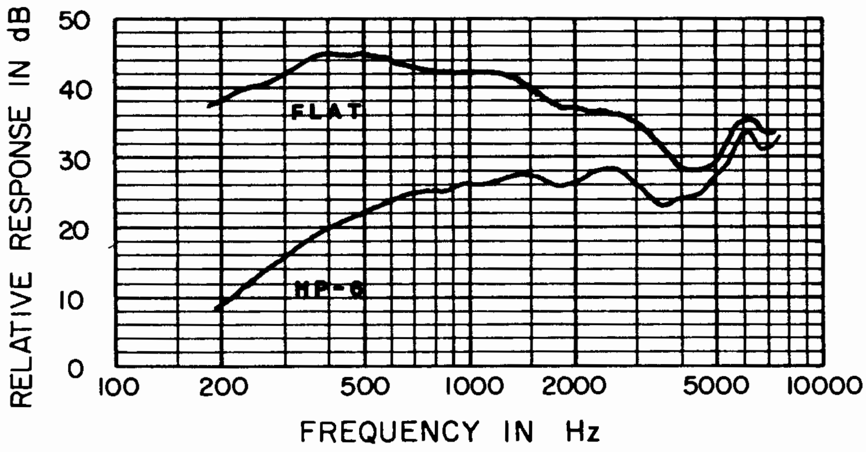


Figure 1. Estimated real ear values for two frequency responses from the "Harvard Report" (after Lybarger, 1978).

A problem with the second omission, failure to consider changes in resonance of the occluded ear canal during hearing aid use, is illustrated in Figure 2 (Pascoe, 1978). This figure shows the mean perceived spectra of speech for

20 normal-hearing listeners in free field. The curve differs from the familiar contour usually seen in that it includes the effects of the head in the sound field and the contribution of ear canal resonance. Further comparison of perceived spectra in Figure 2 obtained from a hearing-impaired listener suggests the harmful effect of occluding the ear canal with a hearing aid earmold, when no efforts are made to compensate for the loss of ear canal resonance.

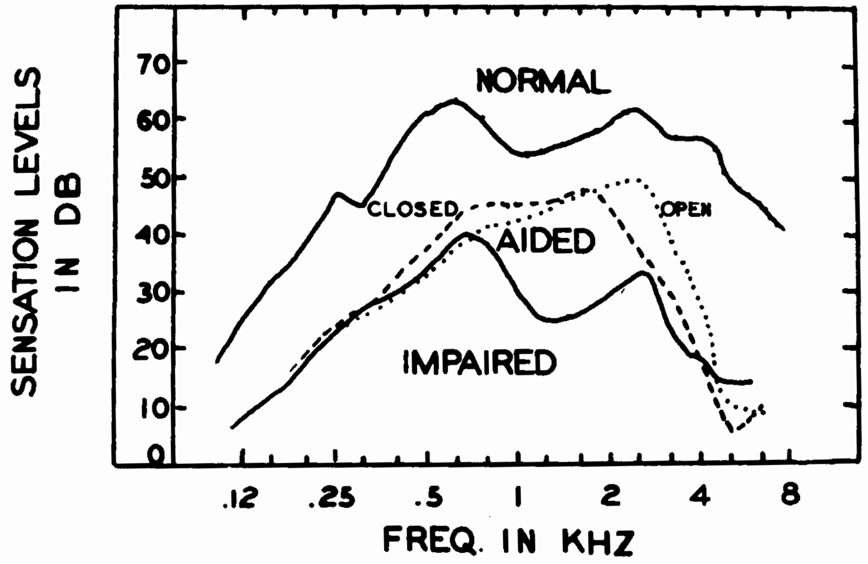


Figure 2. Perceived spectra of summed speech (dB SL) for normal listeners (A), and a hearing-impaired listener aided (B) with a closed and an open ear canal and unaided (C) (from Pascoe, 1978).

Third, the recommendations of the Harvard Report were limited by the fact that the subject population did not include individuals with sharply-falling "ski-slope" sensorineural hearing losses. Such persons were probably not considered hearing aid candidates in that era. Therefore, the inadequacies of a flat frequency response for high-frequency losses were not revealed.

In addition to the bias generated against selective amplification by studies such as the Harvard Report, examiners have been reluctant to use pure tones in reverberant fields because of the fear of calibration problems. This fear has led away from procedures which facilitate measurement of functional gain and selective amplification. As a result, for several years, measures of aided speech discrimination performance provided the primary criteria for the selection of hearing aids.

Research in the 1970s with vented and open vs. standard earmolds again

Table 1
Results of Studies on the Relationship Between
Type of Earmold and Speech Discrimination.

Study	Type of Loss	Discrimination Scores		
		Unaided	Aided	
			Std. Mold	Open Mold
Harford & Dodds, 1968	Sloping S/N	67.7%	71.4%	81.4%[c]
Hodgson & Murdock, 1970	Sloping S/N	71.9%	79.3%	84.7%[c]
Jetty & Rintelmann, 1970	Flat Conductive S/N	95.0%	92.6%	93.6%
	Gradual Slope	79.6%	75.0%	80.0%
	Sharp Slope	69.4%	76.8%	80.0%
		Own Aid[a]		Exp Aid[b]
Harford & Fox, 1978	Sloping S/N	59.8%		73.3%

[a] Frequency Range about 500-4000 Hz.

[b] Frequency Range about 1000-6000 Hz.

[c] Differences between the open and the standard earmold conditions were determined to be significant at or beyond the 0.01 level of confidence.

suggested that shaped high frequency responses were superior, objectively and subjectively, to aids with flat responses. Some of this research is summarized in Table 1. In general, the investigators found better discrimination and comfort when earmolds which de-emphasized low frequency amplification were applied to ears with high frequency sensorineural hearing losses.

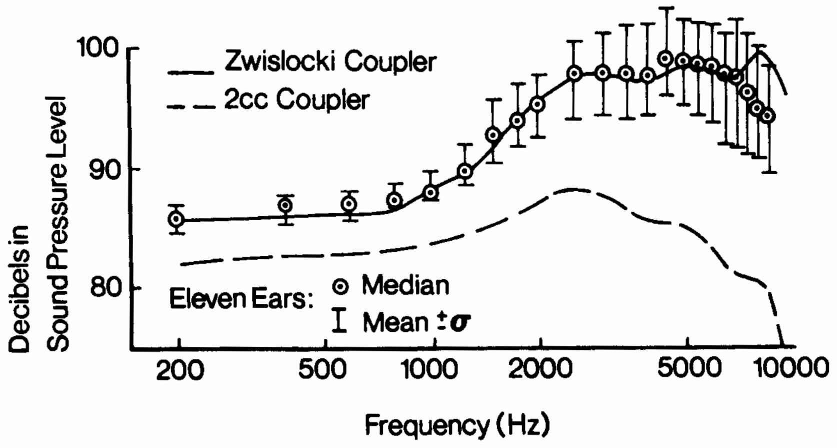
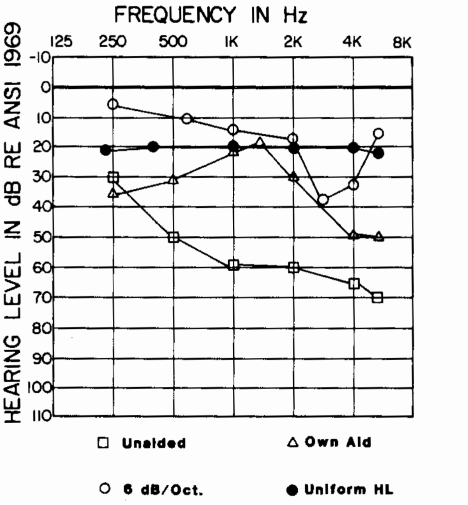


Figure 3. Comparison of responses from Zwislocki and 2 cm³ couplers. In addition to the coupler values, averaged data are shown for eleven real ears (from Sachs & Burkhard, 1972).

Increased awareness of the differences in real ear vs. artificial ear (2 cm^3 coupler) responses led to the realization that aided performance must be sampled with some technique which is not invalidated by these differences. Figure 3 shows frequency response differences between an HA2 type 2 cm^3 coupler and the Zwislocki coupler, representative of an average real ear. The errors thus revealed in selective amplification studies based on 2 cm^3 coupler curves emphasize the need for functional gain measurements. Two methods are currently used. Pascoe (1975) described the use of narrow bands of noise to determine functional hearing aid gain. Harford (1981) reported the use of an ear canal microphone to measure real ear hearing aid gain.

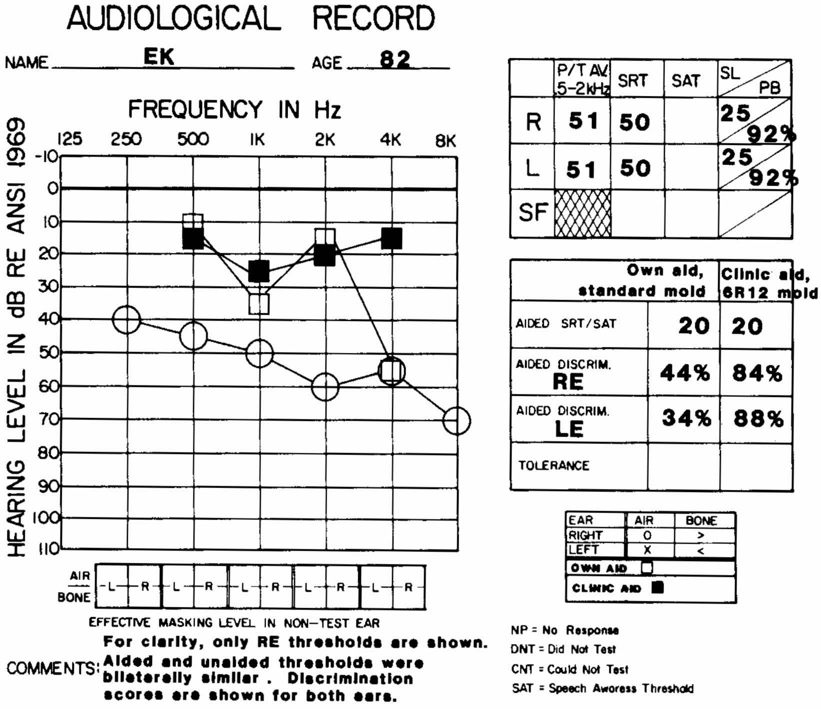
The use of narrow band noise or warble (frequency modulated) tones has proved a practical method for measuring functional gain across frequency. Pascoe (1975) reported for a group of listeners with gradually sloping sensorineural losses, best speech discrimination when a uniform aided hearing level (UHL) was obtained. Figure 4 shows comparative results from frequency response curves representing a rise of 6 dB/octave coupler gain, the subject's own hearing aid, and the aforementioned UHL, with aided thresholds of about 20 dB HL. As indicated earlier, best discrimination scores resulted from the UHL condition. Pascoe (1975) attributed part of the discrimination improvement to the extended high frequency response of the UHL condition, which retained good response to 6000 Hz or higher.



Pascoe,1975

Figure 4. Aided thresholds resulting from three frequency response curves for one hearing-impaired subject. Best intelligibility scores resulted from the Uniform HL condition (after Pascoe, 1975).

This combination, UHL and extended high frequency response, seems to represent a useful pattern for patients with overall reduced auditory sensitivity and gradually sloping configurations. Figure 5 shows an example. The patient's own hearing aids supplied adequate audibility (aided SRTs) for speech, but aided discrimination scores were much poorer than maximum discrimination scores under earphones. Aids with similar overall gain but better high frequency response resulted in much better speech discrimination.



AUDIOLOGICAL RECORD

NAME EK AGE 82

	P/T AV .5-2kHz	SRT	SAT	SL / PB
R	51	50		25 / 92%
L	51	50		25 / 92%
SF	▨			

	Own aid, standard mold	Clinic aid, 6R12 mold
AIDED SRT/SAT	20	20
AIDED DISCRIM. RE	44%	84%
AIDED DISCRIM. LE	34%	88%
TOLERANCE		

EAR	AIR	BONE
RIGHT	O	>
LEFT	X	<
OWN AID ☐		
CLINIC AID ■		

For clarity, only RE thresholds are shown.

COMMENTS: Aided and unaided thresholds were bilaterally similar. Discrimination scores are shown for both ears.

NP = No Response
DNT = Did Not Test
CNT = Could Not Test
SAT = Speech Awaress Threshold

Figure 5. Test results comparing patient's own hearing aid with an aid exhibiting better high-frequency response. Discrimination scores were obtained with recorded W-22 PB lists.

Technical limitations and tolerance problems prevent application of the UHL concept to some patients. These limitations apply to some patients with normal hearing sensitivity across a significant part of the lower audiometric frequencies and a sharply sloping loss of great magnitude in the higher frequencies. Skinner (1980) estimated that problems arise when listeners have sharply sloping losses starting above 1000 Hz and an impairment greater than 40 dB HL at 2000 Hz and above. For such subjects she found best speech discrimination when conversational level speech was amplified, as a function of frequency, to fall within the dynamic range of the listeners in these higher frequencies. An alternative procedure, in such cases, is to amplify that frequency range in which adequate gain is feasible, realizing that technical limitations and tolerance problems may preclude useful gain in higher frequencies where the loss is of great magnitude. To illustrate, Figure 6 shows the audiogram of an individual with normal hearing sensitivity through 2000 Hz who needed amplification because of critical demands on his hearing under moderately difficult listening conditions. In this case, it is unrealistic to expect adequate gain at 4000 Hz where the loss reaches 70 dB HL. Comparison of aided and unaided thresholds at that frequency do not suggest impressive benefits from amplification. However, inspection of the continuous frequency audiogram indicates gain of about 30 dB at the critical frequency of 3000 Hz and an extension upward of the range of audible sounds by about 700 Hz. In fact, the patient is an enthusiastic hearing aid user, reporting improved performance in business conferences and increased ability to monitor production of his own high frequency consonants.

Aids that are currently available have desirable high frequency response characteristics when coupled with appropriate earmolds to exploit this re-

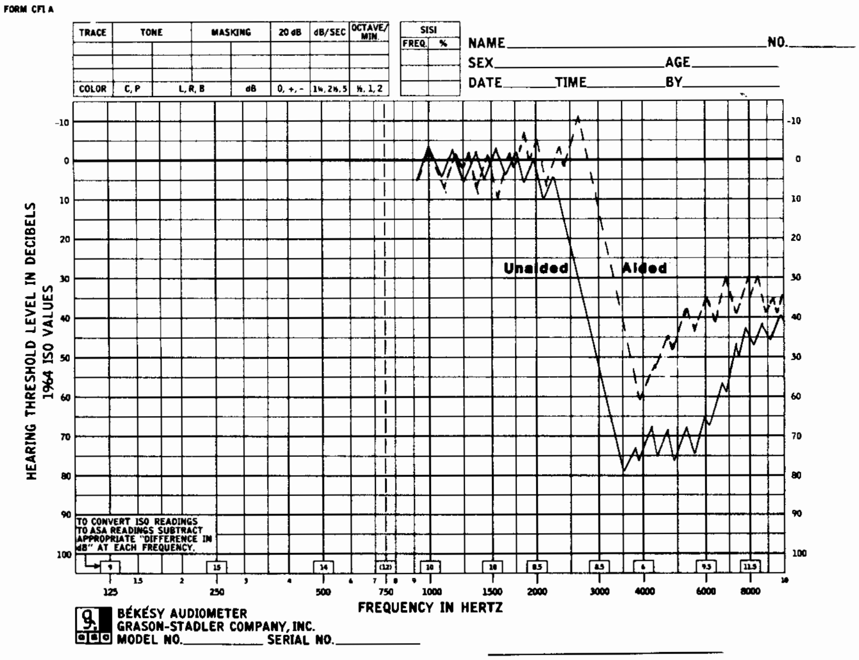


Figure 6. Continuous frequency threshold traces for a patient with high frequency loss.

sponse. Examples of such earmolds are shown in Figure 7. Addition of appropriate dampers to the system smooths the high frequency response and reduces the probability of acoustic feedback problems.

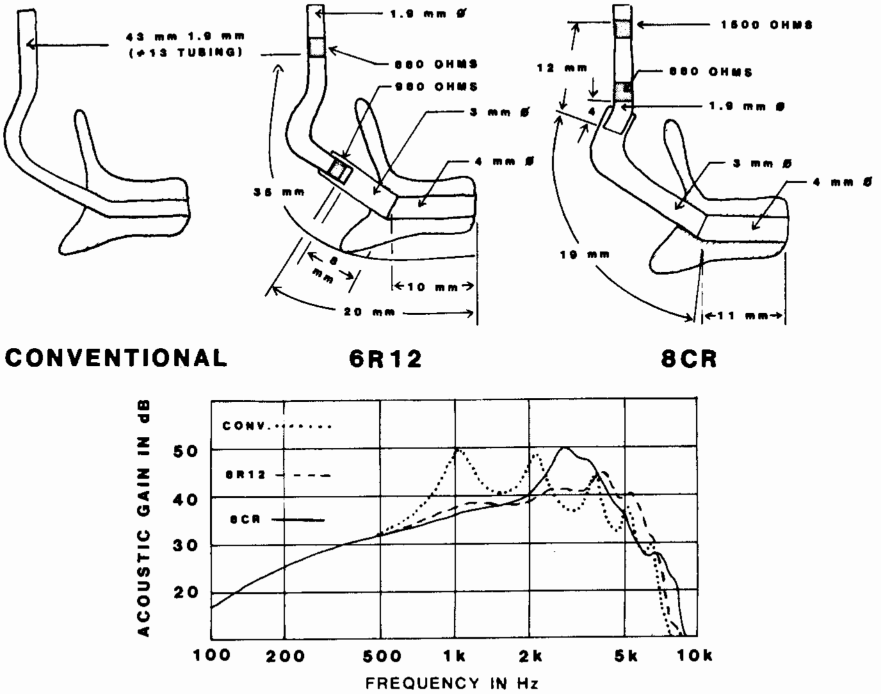


Figure 7. 2 cm^3 coupler response of a wideband receiver with conventional and high-frequency earmolds (from Killion, 1981).

Given the desirability of tailoring the frequency response, a choice between acoustic and electronic modification must be made. Earmold venting is a traditional method for limiting low frequency responses. However, there are disadvantages. The modification afforded by venting is less predictable that that associated with electronic control and, in fact, resonance in parallel vents may actually enhance aided response (vs. the unvented earmold) in the region of 500 Hz. Moreover, use of a side-branch vent may cause undesirable loss of high frequency as well as low frequency energy. When such an effect occurs, feedback may become a concomitant problem, especially if the aid in use has conspicuous high frequency energy peaks. Even if feedback is not audible, Cox (1982) has shown that the presence of sub-oscillatory feedback associated with earmold venting may be responsible for input conditions at the hearing aid's microphone which are quite different from the signal prevailing otherwise.

An understanding of these problems associated with earmold venting, together with increased availability and flexibility of electronic frequency response controls, has led to a movement away from the use of venting. However, Cox and Alexander (Note 1) have shown conditions in which the use of vented earmolds resulted in improved perception of quality as opposed to electronic control of frequency response. Specifically, they concluded that listeners preferred acoustic shaping via venting when hearing sensitivity was normal to 750 Hz, 1000 Hz, or higher. They reported little difference in perceived quality of electronic vs. acoustic shaping of amplification otherwise.

In summary, we have returned to a more accurate use of the concept of selective amplification to achieve appropriate frequency responses. Better methods for assessing functional gain have evolved. Improved flexibility and control of frequency response have resulted.

Further progress is expected through better earphones and improved batteries to supply the power needed for better high frequency systems. Future research should concentrate on the most desirable balance between retaining low frequency responses for good perceived quality and high frequency response for intelligibility, especially in noise. It is possible that signal processing will develop which differentially amplifies various segments of the frequency response under different listening conditions. Innovative use of systems to improve the signal-to-noise ratio may contribute to better amplification. Refinement of these procedures may provide additional information for use in hearing aid evaluations. In conjunction with these electroacoustic and psychoacoustic improvements, we should strive to better understand and guide the psychosocial variables which often prevent a potential amplification candidate from using a hearing aid.

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