Nontraditional Auditory Assessment: Beyond the Audiogram

L'évaluation auditive non conventionnelle : au delà de l'audiogramme

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Abstract

Hearing aid fitting continues to be based primarily on audiometric pure tone thresholds. Although the underlying goal of many prescriptive formulas is improved speech recognition, actual evaluation with suprathreshold stimuli (such as speech) is rare. Furthermore, assessment of benefit from hearing aids in real world environments is often based on nonstandardized anecdotal evidence. The objective of this manuscript is to consider several procedures that may be used to assess hearing aid candidacy and to evaluate benefit from amplification. These measures include: (1) efficient, reliable speech recognition tests; (2) masking pattern data; (3) aided and unaided loudness discomfort measures; (4) self-assessment scales of hearing aid performance; and (5) user selected frequency responses. The feasibility of using each of these measures in clinical practice will be discussed.

Résumé

L'ajustement des prothèses auditives se base principalement sur les seuils auditifs. Même si l'objectif d'un bon nombre de formules prescriptives est d'améliorer l'intelligibilité de la parole, l'évaluation pour les stimuli supra-liminaires (comme la parole) est rare. De plus, l'évaluation des avantages des prothèses auditives dans des contextes réalistes est souvent fondée sur des preuves non scientifiques et non standardisées. Les auteurs examinent plusieurs protocoles pour évaluer la candidature et les bénéfices à l'amplification. Ces mesures comprennent notamment les suivantes : (1) examens vocaux efficaces et fiables pour l'intelligibilité de la parole; (2) données sur l'assourdissement; (3) mesures d'inconfort causé par l'intensité sonore, avec et sans amplification; (4) échelles d'auto-évaluation du rendement des prothèses auditives; (5) réponses fréquentielles préférées par l'utilisateur. Les auteurs abordent la praticabilité de ces mesures en milieu clinique.

Introduction

Current approaches to hearing aid selection and evaluation have undergone many changes, but audiometric thresholds still serve as the primary basis for determining the "optimal" electroacoustic characteristics. The assumption is that, on average, a satisfactory hearing aid fitting will occur when real-ear measurements indicate an adequate match to a preselected prescriptive target. There are several problems with this assumption, however, including that: (1) numerous prescriptive formulas exist; (2) it is difficult to quantify what is meant by an "adequate" match to target gain; and (3) clinicians fit individuals, not KEMAR, and therefore the standard deviation about average may be the statistic of greater interest. The primary issue becomes the accuracy of threshold-based procedures and whether the inclusion of nontraditional auditory assessment ultimately yields greater satisfaction with hearing aids.

Threshold-based Prescriptive Formulas

Clinical real-ear measurements for hearing aid evaluation have popularized the use of prescriptive target formulas that are based on audiometric thresholds. However, considerable confusion has occurred over differences between fitting methods. Disparities across formulas may be accounted for by differences in estimates of speech spectra; furthermore, these discrepancies are minimized by adjustment of the hearing aid volume control wheel. In an attempt to determine whether one method predicts actual hearing aid "use gain" better than others, Fabry and Olsen (1991) compared real-ear use gain settings of 100 hearing aid users to three popular prescriptive target formulae. Subjects were divided into two equal groups who reported overall satisfaction or dissatisfaction with hearing aid performance. Each subject adjusted the hearing aid volume control to use gain for a male talker speaking in a quiet background at approximately 65 dB SPL. Subsequently, real-ear insertion response (REIR) measurements were made for 65 dB SPL composite noise inputs and compared to the predicted insertion gain values for NAL-R (Byrne & Dillon, 1987), Berger (Berger, Hagberg, & Rane, 1978), and POGO (McCandless & Lyregaard, 1983) prescriptive target values.

Rms differences were computed between measured insertion gain and target gain for each of the three formulas for 250, 500, 750, 1000, 1500, 2000, 3000, and 4000 Hz (Figure 1). Results are summarized in Figure 2; the rms error between insertion gain (at user-adjusted volume control setting) and prescriptive targets was significantly greater for subjects unhappy with hearing aids than for those satisfied with hearing

Figure 1. Example of the method used for computing the rms error between real-ear insertion response (REIR) at user-adjusted volume control setting (open circles) and NAL prescriptive target (dashed line).

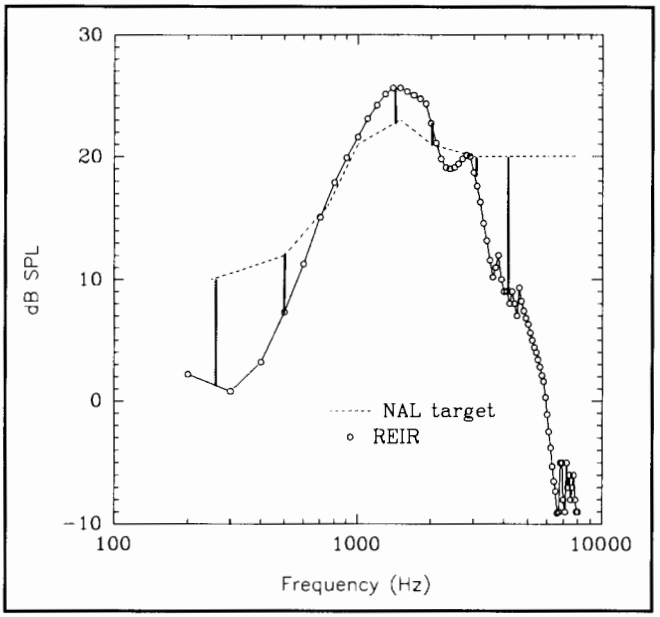
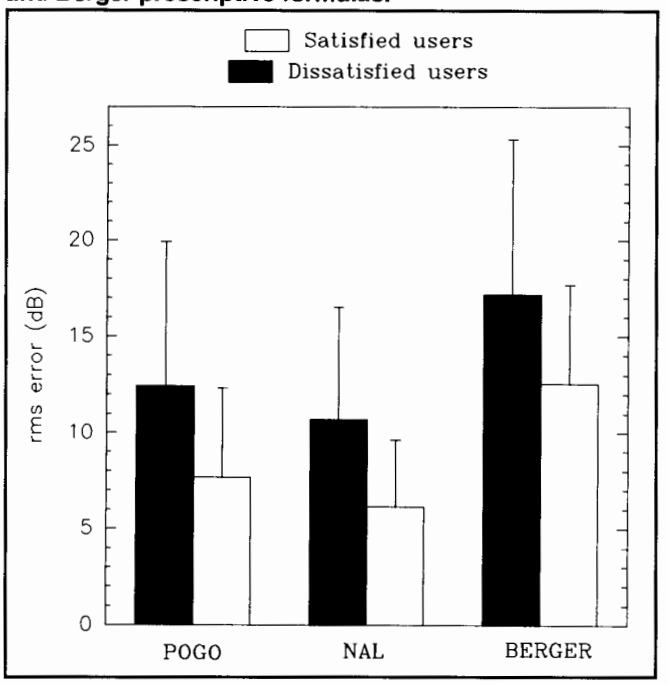


Figure 2. Mean rms error for satisfied (open bars) and dissatisfied (filled bars) hearing aid users for POGO, NAL, and Berger prescriptive formulas.



aid performance ($p<.05$). For subjects who were generally satisfied with their hearing aids, the overall rms error was smallest between insertion gain and NAL-R target (6.13 dB). These data indicate that auditory threshold, on average, served as a reasonable basis for selecting the appropriate gain-by-frequency settings. Inter-subject differences were substantial, however, indicating that factors other than auditory threshold contribute to overall hearing aid satisfaction.

Speech Measures

Speech recognition measures long have been criticized for their lack of clinical utility; test-retest reliability is often at odds with efficient administration of a practical number of test items. Furthermore, the issue of face validity is raised frequently as an argument for using materials similar to those encountered with everyday speech (Cox, Alexander, & Rivera, 1991). Although the medically published method for determining speech handicap is for speech intelligibility in quiet (Journal of the American Medical Association, 1979), more hearing impaired persons complain of difficulty with speech in noise.

Speech intelligibility in noise is dependent on a variety of acoustic, non-acoustic, and random factors. Some of the acoustic factors include the level and frequency spectrum of speech and noise, the temporal pattern of speech, and the reverberation present in the listening environment (ANSI, 1977). Nonacoustic factors affecting speech recognition in noise include contextual cues, the size of the message set, the homogeneity of test items, and familiarity between the talker and listener. Random factors include differences in spectra across talkers or within the same talker across days or listening environments, the listener's motivation, or lapses in concentration.

In fact, the ideal set of speech materials does not exist. Rather, stimuli should be selected to be optimal for a given task. Several procedures in use clinically at our facility are highlighted in the next paragraphs. Regardless of the selection, it is imperative that recorded materials be used, when possible, to minimize the effects of some random factors. Fortunately, because of inexpensive digital-to-analog convertors, compact disk players, and digital audio tape, recorded media are available that provide random access, excellent signal-to-noise ratios and flexibility for adapting to different cadences across patients.

SRT in Noise

Plomp's (1978) model of hearing loss attempts to predict performance in a range of noisy environments. The basis of the model is measurement of speech reception threshold (SRT) for words or sentences in quiet and at a fixed noise level. Van Tasell and Yanz (1987) provide a demonstration of the effects of hearing loss, frequency response, and speech materials on SRT measures for spondaic and monosyllabic words. Van

Tasell and Yanz reported that SRTs for spondees and monosyllables using the simple up-down method (Levitt, 1971) were more sensitive to changes in low- and high-frequency amplification, respectively. Their conclusions were that the "speed, reliability, and apparent sensitivity of the SRT in quiet and noise to frequency response characteristics make it a potentially useful tool for hearing aid evaluation" (Van Tasell & Yanz, 1987, p. 377). In addition, they stressed the importance of selecting a closed-set list of words that is highly homogeneous for intelligibility. Recently, Nilsson, Sullivan, and Soli (1991) have developed a sentence test, based on the Bamford, Kowal, and Bench (BKB) sentences (Bench, Kowal, & Bamford, 1979), which contains individual sentences that are equated for difficulty. This test offers high face validity in addition to the other advantages of SRT in noise with spondees or monosyllables.

Rated Intelligibility

Another method for achieving high face validity is via subjective ratings of speech intelligibility. Cox and McDaniel (1984; 1989) developed the Speech Intelligibility Rating (SIR) test in an attempt to provide a set of connected discourse passages that would optimize test reliability and face validity in one set of speech materials. The SIR comprises 20 passages of connected discourse that have been equated for intelligibility and duration; each passage is 48 seconds long and is paired with a segment of multitalker babble of equal duration. The listener's task is to rate the intelligibility of individual passages in quiet or in babble on a scale from zero to 10.

Cox and McDaniel (1989) standardized the SIR for subjects with normal hearing and determined that the 90% confidence interval for two scores (based on three ratings each) was 1.8 scale units. That is, 90% of the time, two scores (averaged from three ratings each) that differ by a minimum of 1.8 will be truly different from each other. McDaniel and Cox (1992), using hearing impaired subjects, reported 90% confidence intervals of 1.75 scale units for the average of five ratings.

Surr and Fabry (1991) compared SIR ratings from hearing impaired subjects who rated the intelligibility of three high-frequency emphasis hearing aids that differed in mid-frequency amplification. Their data suggested that the SIR test was not sensitive to differences in frequency response slopes of 6 to 14 dB/octave between 1000 and 2000 Hz. Although rated intelligibility tests promise high face validity, the stimuli must be highly homogeneous for intelligibility and context to minimize inter- and intra-subject variability. In addition, more time is required for completion of the SIR than for SRT in noise because three or more passages must be presented to obtain a stable average rating.

Speech Perception in Noise (SPIN)

The SPIN was originally developed by Kalikow, Stevens, and Elliott (1977) in an attempt to provide a solution to many of the problems with word list tests. Bilger, Neutzel, Rabinowitz, and Rzecozowski (1984) standardized the SPIN materials for use with hearing impaired listeners. Each 50-item list comprises 25 high-probability and 25 low-probability sentences; the listener's task is to identify the final word of each sentence when presented in a background of multi-talker babble. The relationship between scores on low- and high-probability test items may provide information about the validity of an individual's score, as well as the person's ability to use contextual information. Bilger et al. (1984) used a signal-to-babble ratio (S/B) of +8 dB, which was reported by Pearsons, Bennett, and Fidell (1977) to be the median "real-world" S/B.

In summary, several new speech measures offer promising opportunities for assessment of speech recognition scores under standardized conditions in realistic listening environments.

Assessment of Frequency Resolution Via Masking Patterns

The recent trend of using adaptive high-pass filter circuits in hearing aids has suggested that speech intelligibility in noise may be improved with these devices over conventional hearing aids. Data that have compared adaptive frequency response (AFR) hearing aids to conventional fixed frequency response (FFR) hearing aids fail to support these claims under most listening conditions (Van Tasell, Larsen, & Fabry, 1988). For some band-limited, low-frequency noises, however, improvements can occur; presumably, this is due to release from upward spread of masking (Bilger & Hirsh, 1956) for AFR conditions. The results of at least two recent studies (Gagné, 1988; Trees & Turner, 1986) indicate that some hearing impaired subjects may suffer from upward spread of masking effects in excess of those predicted by audiometric thresholds.

In an attempt to quantify the relationship between upward spread of masking, AFR hearing aids, and speech recognition in noise, Fabry, Leek, and Walden (1990) measured masking patterns in ten subjects with precipitous high-frequency hearing loss. Masking patterns were measured (using sinusoidal stimuli and Bekesy tracking) for simulated single-microphone FFR and AFR conditions in the presence of a low-frequency noise with cutoff frequency at 1000 Hz and filter slope in excess of 100 dB/octave. In addition, monosyllabic word recognition was assessed under both conditions. Results indicated a modest correlation (r=0.61) between release from upward spread of masking at 1500 Hz and improved mono-

Figure 3. Data compare the change in masked threshold at 1500 for AFR-on and AFR-off conditions to the percent change in speech recognition scores under the same conditions. Data on the ordinate are the AFR-on masked thresholds minus AFR-off thresholds for the same subject. Data on the abscissa are the difference in speech recognition for AFR-on minus AFR-off conditions.

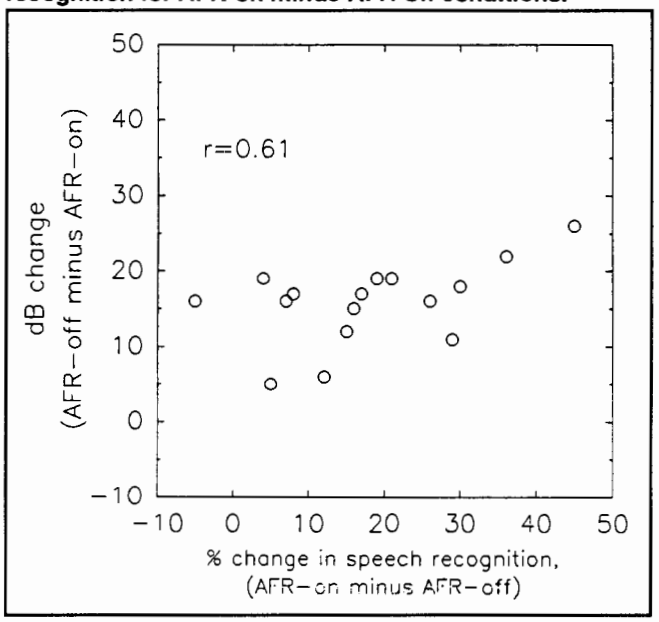
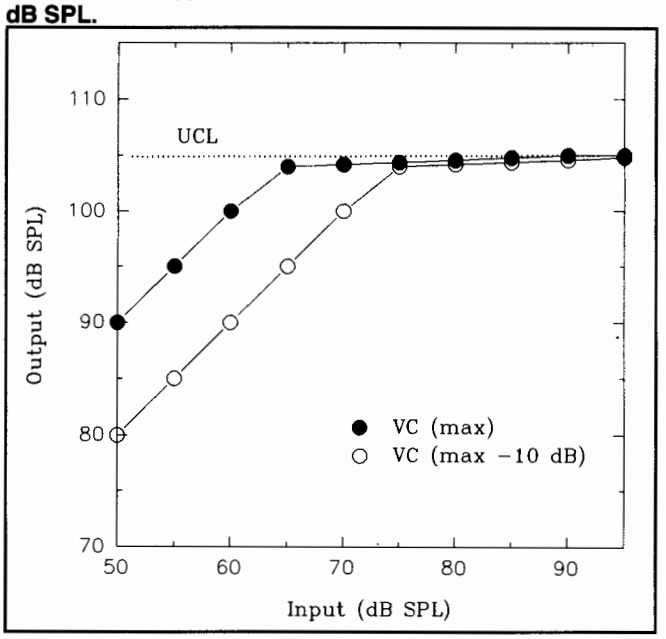


Figure 4. Input/output functions for an output compression hearing aid with compression threshold set to 104 dB SPL (compression ratio is 10:1) for full-on gain (filled circles) and for 10 dB less gain in linear mode (open circles). The hypothetical hearing aid user's UCL is 105 dB SPL.



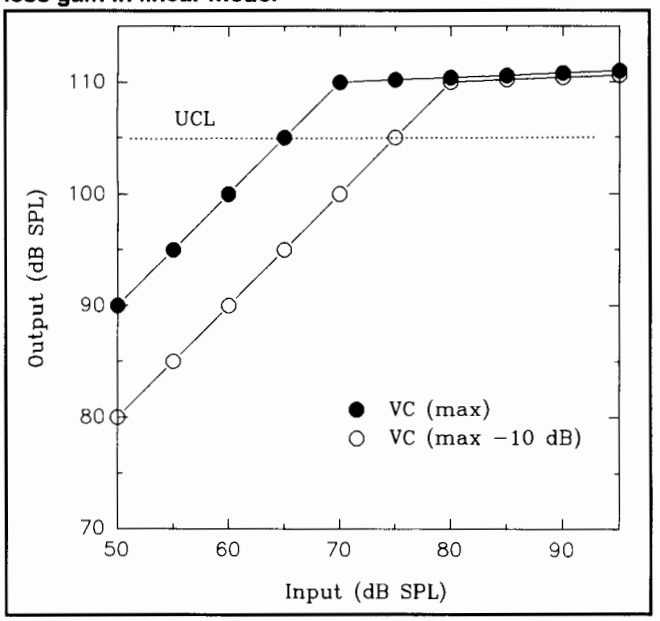
syllabic word recognition for the AFR versus FFR condition (Figure 3). This was, however, substantially higher than the correlation between auditory threshold (at 1500 Hz) and improved speech recognition scores for AFR versus FFR, which was 0.21. The efficacy of developing a screening measure of frequency resolution to determine candidacy for AFR hearing aids seems worthy of further evaluation.

Loudness Discomfort Measures

Measurement of maximum hearing aid output is equal to, or more important than, assessment of gain-by-frequency characteristics (Hawkins, Walden, Montgomery, & Prosek, 1987). Estimates of expected aided loudness discomfort levels (LDL) may be made prior to fitting and confirmed via real-ear saturation response (RESR) measurements, but they are often an ignored element of the hearing aid test battery.

Motivation for assessment of aided LDLs is provided by Kamm, Dirks, and Mickey (1978) who report, "The nonlinear relationship between LDL and hearing loss ... suggests that prediction of LDL from hearing threshold would often be highly inaccurate"(p.668). Further incentive is provided by the recent success with programmable input compression hearing aids and hearing aids with Class D output receivers. The frequency responses from these devices are not inherently superior to those available from conventional peak clipping or output compression hearing aids. However, there is an important difference in the way hearing aid saturation sound pressure level (SSPL90) interacts with volume control adjustments. For peak clipping or output compression devices (Figure 4), maximum hearing aid output is independent of volume control setting. As a result, if SSPL90 is set to limit sounds from exceeding the user's uncomfortable loudness level (UCL), the hearing aid may be in saturation for most input stimuli when set to full-on volume, and sound quality may suffer. If, on the other hand, the SSPL90 on a peak clipping or output compression hearing aid is set inappropriately high (Figure 5), some sounds will exceed the person's UCL, regardless of volume control setting. For input compression devices and some Class D hearing aids (Figure 6), however, maximum hearing aid output is dependent on volume control setting. Consequently, for input compression hearing aids, the *user* controls hearing aid gain and output for different listening environments; this may contribute, in part, to the recent commercial success of these devices over the peak clipping hearing aids that dominate the market. However, better assessment of aided real-ear uncomfortable loudness (UCLs) may provide more accurate fitting of these conventional hearing aids. There have been wide ranging debates over the merits of narrow- versus broad-band stimuli for assessment of UCL. An excellent summary of the issues is provided by Stelmachowicz (1991). The bottom line is that for most conventional hearing aids, SSPL90 adjustments are not frequency specific, and therefore the highest level to which SSPL90 should be set is dependent on the resonant frequency producing highest output.

Figure 5. Input/output functions for an output compression hearing aid with compression threshold set to 110 dB SPL (compression ratio of 10:1) for full-on gain (filled circles) and with the volume control set to provide 10 dB less gain in linear mode.

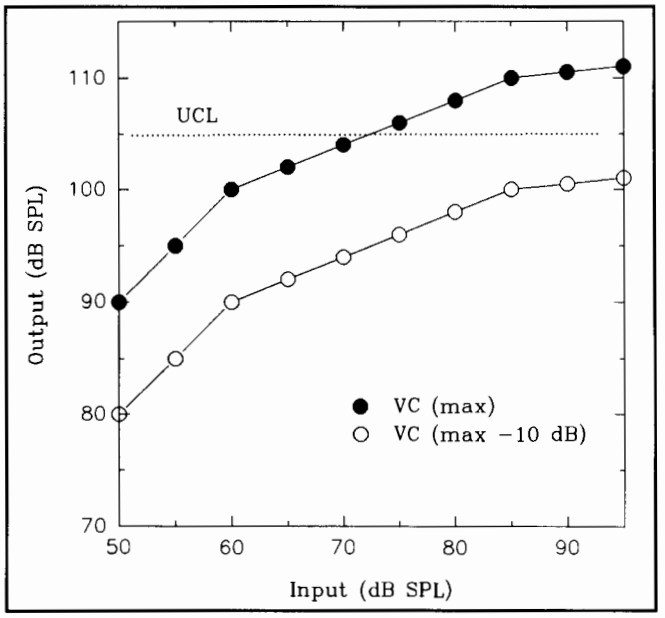


A procedure similar to the approach used by Hawkins (1983) is recommended for measurement of UCL and subsequent determination of hearing aid SSPL90. For clinical confirmation, we recommend that an aided RESR measurement be made with composite noise, and the frequency of maximum aided output be used as the stimulus to adjust SSPL90 to below UCL. These measurements should be made with the volume control wheel adjusted to maximum setting before feedback occurs. The same procedure may be used for hearing aids with frequency-dependent control of SSPL90, for example, those with multiple compression bands, but peak levels in several frequency regions may be selected as stimuli. After final adjustments, another RESR measurement may be made with broad-band stimuli to verify that the intended result was achieved and that loudness summation across frequencies does not exceed UCL.

Self-Assessment Scales

The primary goal of hearing aid fitting procedures is to maximize speech intelligibility; however, hearing aid satisfaction may be determined by a combination of speech intelligibility, sound quality, and other factors. Furthermore, as was discussed previously, clinical speech measures may not be sensitive to subtle effects that distinguish one hearing aid from another. Also, the ultimate determination of hearing aid satisfaction — whether or not the person purchases the hearing aid — resides with the user's opinions about perceived benefit from amplification.

Figure 6. Input/output functions for a hearing aid with input compression thresholds at 60 dB SPL (3:1 compression ratio) and 85 dB SPL (10:1 compression ratio) for a hearing aid at full-on volume (filled circles) and with the volume control wheel set to provide 10 dB less gain (open circles). The hypothetical hearing aid user's UCL is 105 dB SPL.



Several questionnaires have been developed for self-assessment of hearing aid benefit (Walden, Demorest, & Hepler 1984; Cox & Gilmore, 1990). Recently, we have used the Profile of Hearing Aid Performance (PHAP), developed by Cox and Gilmore (1990), to supplement objective measures of speech recognition for several hearing aid clinical field trials. The PHAP consists of 66 statements that comprise communication under a variety of listening environments. Hearing impaired persons respond to each statement, based on their everyday experience, using a seven point scale, based on frequency of occurrence, that ranges from "always" (99%) to "never" (1%). The 66-item test is divided into seven subscales combined into four scales. Cox and Gilmore have standardized the test on a group of hearing impaired subjects, allowing both intra- and inter-subject comparisons to be made for hearing aid conditions.

An example of such comparisons is shown in Table 1 for a group of three (out of ten total) subjects who compared two hearing aids that were matched for gain and output at 50 and 90 dB SPL inputs but differed in compression threshold and compression ratio (Fabry & Olsen, 1991). One device employed full dynamic range compression, and the other used input compression limitation. Subjects were fit with each hearing aid for a period of one month; subsequently, they were evaluated with the SPIN and PHAP tests, and were ultimately forced to choose between the two hearing aids as

Table 1. PHAP scores for hearing aids with similar frequency responses, but with either full dynamic range (FDR) or input limiting (IL) compression. The 90% critical differences (Cox & Gilmore, 1990) are indicated in parentheses; asterisks indicate that difference scores between two conditions exceed 90% values.

Subject	Condition	Scale (90% critical difference) SA(13.5)	SB(16.7)	SC(15.2)	EN(19.1)
T	FDR	16.0	50.4	50.6	56.2
	IL	15.0	47.6	40.5	30.2*
K	FDR	21.5	36.4	63.8	45.7
	IL	8.1	30.3	43.6*	29.6
C	FDR	32.1	49.8	59.9	47.5
	IL	30.1	40.8	75.5	71.0

Table 2. PHAP scores for hearing aids with the same frequency responses, but with either fixed release (FR) or adaptive release (AR) from compression. The 90% critical differences (Cox & Gilmore, 1990) are indicated in parentheses; asterisks indicate that difference scores between two conditions exceed 90% values (none shown).

Subject	Condition	Scale (90% critical difference) SA(13.5)	SB(16.7)	SC(15.2)	EN(19.1)
I	FR	27.6	50.7	42.9	27.7
	AR	23.1	50.6	42.9	23.6
O	FR	15.0	35.2	35.6	19.2
	AR	16.1	36.8	35.1	24.1
C	FR	21.2	32.1	34.7	25.0
	AR	22.1	35.2	32.1	25.5

the "preferred device if these were the only options for hearing aid use." SPIN results showed no significant differences between the two types of compression devices, but the PHAP scores from scale ES (environmental sounds) indicated agreement with nine of ten subjects' overall preference.

Another evaluation in progress at our clinic compares two hearing aids matched in frequency response that used either fixed- or adaptive-release times for compression. Preliminary results from this study reveal excellent test-retest PHAP scores (over one month's time) from several persons who reported no perceived differences between the two hearing aids (Table 2). Additional data are required to determine whether long-term changes in hearing aid satisfaction are reflected in PHAP scores and also to determine the efficacy of unaided, baseline PHAP scores. Cox and Gilmore (1990) also described another index derived from the PHAP, called the Profile of Hearing aid Benefit (PHAB), for use in making direct comparisons between unaided and aided conditions. The difference between aided and unaided responses is the measure of hearing aid benefit.

User-Selected Frequency Responses

The advent of multiple memory programmable hearing aids has created a dilemma for the dispensing audiologist: After the predetermined set of prescriptive target gain values has been programmed into one hearing aid memory, what should the other memories contain? To date, there are no published guidelines for empirically determining the optimal hearing aid electroacoustic parameters for any input signals besides speech in quiet.

Recently, Fabry and Stypulkowski (1992) conducted a study that evaluated user-selected gain-by-frequency responses as a viable solution to the problem of programming multiple frequency responses for an individual hearing aid user. In that study, only two variables were manipulated: overall gain in the low- and high-frequency bands of a commercially available programmable hearing aid. Subjects selected the preferred frequency response for three different listening environments: speech in quiet, speech in noise, and recorded music. Subsequently, the user-selected response for one of the three listening environments, for example, speech in noise, and the subject's NAL-R prescriptive target were programmed randomly into the hearing aid's memories. Subjects then wore the device for two weeks, but only for listening situations when background noise was present. Subjects were instructed to alternate between memories to find the preferred frequency response for listening to speech in noise. This procedure was repeated for the other two listening environments (speech in quiet and recorded music). Fabry and Stypulkowski's conclusions included the following: (1) in the laboratory, subjects selected frequency responses that differed in low- and high-frequency gain for listening to speech in quiet and in background noise; (2) user-selected frequency responses differed from NAL-R target gain to varying degrees, with the greatest discrepancy for speech in noise; and (3) in real-world environments, seven of nine subjects used the gain-by-frequency response settings that they selected in the laboratory more than the NAL-R settings.

Conclusions

The recent advances in hearing aid technology, including those devices that offer multiple frequency responses and input compression, require that new techniques be developed for hearing aid evaluation that consider more than audiometric thresholds measured in quiet backgrounds. These procedures may include the development of new tests of frequency and temporal resolution, as well as more sophisticated methods

for assessment of speech intelligibility. As always, clinical considerations require that the tests be accurate, reliable, and easily and rapidly administered.

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