Evaluation of Prescriptive Fitting
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Abstract
The purpose of this study was to determine the minimum tolerance needed when choosing a manufacturer who custom-built analog circuitry for all-in-the-ear hearing aids to match a popular prescriptive amplification formula. Given the tolerance, a second purpose was to evaluate fitting success by calculating the differences in prescribed versus preferred gain and pre-versus postfitting perceived benefits. Eight elderly adults with mild to moderate sensorineural hearing losses participated. Real ear measurements were obtained via a probe-tube microphone system. Even when providing for the optimal scenario of custom-building the circuitry, the inherent limitations of analog technology allowed no better than a ±12 dB electroacoustic match to prescribed gain. Although the minimum tolerance found was less than previous studies, it was still considered excessive given the differences in prescribed gain among formulae. Regardless of the large tolerance and a preference for less gain than prescribed, the subjects reported substantial benefit with the fitting approach.

Key Words: Prescriptive amplification, real ear measures, minimum tolerance, preferred gain, perceived benefit

The use of prescriptive formulae in the determination of appropriate gain, frequency response, and maximum output has gained widespread acceptance. Since the rediscovery of prescriptive fitting in the late 1970s and the advent of the computerized probe-tube microphone system in the early 1980s, numerous prescriptive procedures have been promoted.

Most formulae utilize pure-tone thresholds for prescribing appropriate amplification (Berger, 1976; McCandless and Lyregaard, 1983; Byrne and Dillon, 1986; Libby, 1986). Other formulae take into account a patient's most comfortable listening level or similar comfort threshold measure (Skinner et al, 1982; Cox, 1983). Regardless of formula differences, their attraction is in providing the clinician with a greater degree of objectivity in amplification fitting. The probe-tube microphone system has not only made hearing aid fitting expedient and reliable, it has facilitated our use of otherwise cumbersome prescriptive formulae.

However, what we prescribe and subsequently order from the hearing aid manufacturer versus what we actually receive can be substantially different. Punch (1987) investigated how well commercial behind-the-ear instruments matched prescribed gain as a function of audiometric configuration. He found that a minimum gain tolerance of ±12 dB was necessary in order to provide a reasonable fitting from a reasonably sized consignment stock. Bratt et al (1987) likewise attempted to determine the tolerance for all-in-the-ear hearing aids. They found that a tolerance of ±19 dB was needed if 90 percent of the hearing aids were to meet the targeted gain criteria. Although little is known regarding an acceptable tolerance for any particular formula, the tolerances found in these two studies appear substantial.

As noted in the Bratt et al (1987) study, hearing aid manufacturers typically construct all-in-the-ear aids from preassembled components following family-of-curve matrices. However, it is becoming more common for manufacturers to provide an option to the use of preassembled circuits, and that is to custom build the hearing aid circuitry. Thus, it might be assumed that the option of custom built circuitry would provide a closer match to the prescribed gain and result in a reduction of the necessary tolerance.

Although determination of an acceptable tolerance is important in assessing the validity of the numerous prescriptive procedures, other criteria such as differences in preferred versus
prescribed gain and pre- to postfitting questionnaires can also contribute to evaluating the success of amplification fitting. Therefore, the intent of this investigation was to determine: (1) the difference in ordered versus received 2 cm³ coupler gain and maximum output when utilizing the option of custom built circuitry in all-in-the-ear hearing aids, (2) the difference in target insertion gain from best-fit insertion gain following adjustment of hearing aid potentiometers and venting, (3) whether hearing impaired subjects preferred more or less gain than prescribed, and finally, (4) whether or not subjects obtained substantial benefit from their hearing aid fitting given the variance of their best-fit insertion gain from the target insertion gain.

**METHOD**

**Subjects**

Eight adult subjects aged 60 to 74 years with a mean age of 69 years participated in this study. The typical audiometric pattern was a mild sloping to moderate sensorineural hearing loss in the test ear. Speech recognition scores were reasonably consistent with the degree of sensitivity loss without significant central involvement. In Figure 1, the mean audiogram is displayed. One subject was fit binaurally and thus both ears were included for a total of nine ears. All subjects were considered appropriate candidates for all-in-the-ear amplification. Three of the subjects were experienced hearing aid wearers, the remaining five were initially fit with amplification.

**Equipment and Procedure**

Following the determination of hearing aid candidacy, all subjects responded to the Hearing Handicap Inventory for the Elderly (HHI-E) to assess the patient's perceived communication handicap prior to amplification fitting (Ventry and Weinstein, 1982). The experienced wearers were instructed to answer the questions according to the way they hear without a hearing aid.

The Rastronics PortaREM 20 probe-tube microphone system was utilized to obtain the real ear unaided response (REUR), the target full-on gain and maximum output in a 2 cm³ coupler for each subject. The REUR was incorporated into the formula for determining target full-on gain rather than using an averaged REUR such as the KEMAR response in order to reduce the fitting error for subjects with atypical REURs (Mueller, 1989). The revised formula of the National Acoustics Laboratory (NAL) developed by Byrne and Dillon (1986) was utilized in calculating the target 2 cm³ coupler full-on gain. Maximum SSPL90 values were calculated by determining each subject's loudness discomfort level for pure tones under earphones and then converting those levels to 2 cm³ coupler values.

A hearing aid manufacturer with whom we have a good working relationship and who uses the revised NAL formula for hearing aid assembly was selected to construct the hearing instruments. The company provides dispensers with a choice of the typical matrix fitting or the custom-built circuit fitting option. By requesting the custom-built circuit option, the manufacturer experiments with various electronic components to best approximate the target 2 cm³ coupler full-on gain and maximum SSPL90 values. The company stated that although larger and smaller values are not infrequent, a ±5 dB tolerance should be expected for the matrix fitting option. Albeit more expensive, one should expect a reduced tolerance with minimal deviation from that tolerance if one chooses the custom-built circuit option. For this investigation, the custom-built circuit option was chosen for all subjects in order to assure us of receiving as close an electroacoustic match as possible with analog circuitry. Frequency response and maximum power output trimpots as well as venting were ordered as needed.

Upon receipt of the hearing aid, each subject returned to the clinic to be fit via the probe-tube system using their own REUR in a calculated target insertion gain per the revised NAL formula. Trimpots and venting were adjusted to provide a best-fit insertion gain approximating the target insertion gain.

![Figure 1](image-url)  
**Figure 1** Mean hearing loss of the subject group. Bars equal ±1 standard deviation.
Following a 30-day trial period, each subject returned to the clinic once again where preferred gain was measured and the post-fitting evaluation with the HHI-E was administered. The preferred gain was obtained by first ensuring that each subject had the volume control at their typical daily wear setting. The aid was then removed and evaluated in the hearing aid test box at that setting. The preferred gain was subsequently compared to the target gain. The subjects answered each item on the HHI-E according to the way they hear with their hearing aid.

**RESULTS**

**Coupler and Insertion Gain Differences**

Ordered 2 cm³ coupler values of maximum SSPL90 and target full-on gain were compared to received values using the manufacturer’s own specification printouts. The reason for using the manufacturer’s printouts was to eliminate potential error of interfacility measurement differences.

As audiologists, our primary concern when ordering maximum SSPL90 values based on a patient’s loudness discomfort level is to insure that received values do not exceed what we ordered. Table 1 is a listing of the decibel amount by frequency that each hearing aid exceeded the prescribed SSPL90 value. Three of the nine hearing aids had values exceeding what was prescribed. In addition, all three aids had values at one frequency that were greater than five decibels over the prescribed SSPL90 values. In the majority of cases, the excessive output would pose limited difficulty in that one would make an adjustment to the output limiter trimpot. Unfortunately, one of these three aids did not have an SSPL90 trimpot and thus further adjustment at the time of fitting could not be made.

Table 2 is a display of the 2 cm³ coupler difference values for full-on gain. Errors of too much as well as too little gain are equally spread throughout the frequency range of 250 Hz through 3000 Hz. As might be expected, errors of too little gain dominate at 4000 and 6000 Hz. Mean differences approximate 5 dB with a slightly smaller standard deviation for all frequencies with the exception of 6000 Hz.

Upon return to the clinic, each subject had their target insertion gain calculated and the hearing aid fit to their ear. The hearing aid trimpots and venting were adjusted to provide a best-fit real ear insertion response (REIR). The data shown in Table 3 are difference values for insertion gain. Once again, errors of too much or too little gain are distributed through-

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**Table 1** Received SSPL90 Values (dB) Exceeding Ordered SSPL90 Values

<table>
<thead>
<tr>
<th>Subjects</th>
<th>MM</th>
<th>EF</th>
<th>CL</th>
<th>BM</th>
<th>WM</th>
<th>LP</th>
<th>AA(1)</th>
<th>AA(2)</th>
<th>EW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (kHz)</td>
<td>0.5</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
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<td></td>
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<tr>
<td>1.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>0</td>
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<td>0</td>
<td>0</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>3</td>
<td>8</td>
<td>2</td>
<td>2</td>
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<td></td>
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<td>0</td>
<td></td>
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</table>

Values not listed were not obtained.

**Table 2** Coupler Difference Values (dB) for Ordered versus Received Full-On Gain

<table>
<thead>
<tr>
<th>Subjects</th>
<th>.25</th>
<th>.5</th>
<th>.75</th>
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<th>2</th>
<th>3</th>
<th>4</th>
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<tr>
<td>Frequency (kHz)</td>
<td></td>
<td>5</td>
<td>6.0</td>
<td>4.22</td>
<td>3.44</td>
<td>4.11</td>
<td>6.67</td>
<td>4.67</td>
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<tr>
<td>Mean</td>
<td>5.00</td>
<td>6.00</td>
<td>4.22</td>
<td>3.44</td>
<td>4.11</td>
<td>6.67</td>
<td>4.67</td>
<td>3.56</td>
</tr>
<tr>
<td>SD</td>
<td>3.08</td>
<td>5.05</td>
<td>2.91</td>
<td>2.13</td>
<td>3.18</td>
<td>3.91</td>
<td>3.24</td>
<td>2.56</td>
</tr>
<tr>
<td>Min</td>
<td>-10</td>
<td>-7</td>
<td>9</td>
<td>-7</td>
<td>-5</td>
<td>-8</td>
<td>-8</td>
<td>-6</td>
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<tr>
<td>Max</td>
<td>9</td>
<td>18</td>
<td>9</td>
<td>4</td>
<td>12</td>
<td>14</td>
<td>8</td>
<td>6</td>
</tr>
</tbody>
</table>

Negative values indicate received gain was less than ordered gain. Absolute values were used to compute means and standard deviations.
Table 3  Difference Values (dB) for Target Insertion Gain versus Best-Fit Insertion Gain Following Hearing Aid Adjustment

<table>
<thead>
<tr>
<th>Subjects</th>
<th>25</th>
<th>5</th>
<th>75</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>6</th>
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<tr>
<td>CL</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>-10</td>
<td>5</td>
<td>0</td>
<td>-1</td>
<td>-10</td>
<td>-8</td>
</tr>
<tr>
<td>WM</td>
<td>0</td>
<td>0</td>
<td>-2</td>
<td>-2</td>
<td>10</td>
<td>0</td>
<td>-5</td>
<td>-12</td>
<td>-3</td>
</tr>
<tr>
<td>EW</td>
<td>-4</td>
<td>3</td>
<td>0</td>
<td>-2</td>
<td>1</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>-3</td>
</tr>
<tr>
<td>LP</td>
<td>1</td>
<td>-12</td>
<td>-7</td>
<td>-1</td>
<td>8</td>
<td>6</td>
<td>0</td>
<td>-12</td>
<td>-26</td>
</tr>
<tr>
<td>BM</td>
<td>0</td>
<td>0</td>
<td>-3</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>-7</td>
<td>-4</td>
<td>-15</td>
</tr>
<tr>
<td>AA(1)</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>-3</td>
<td>0</td>
<td>3</td>
<td>-1</td>
<td>-5</td>
<td>-2</td>
</tr>
<tr>
<td>AA(2)</td>
<td>-2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
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<td>-8</td>
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<td>-20</td>
</tr>
<tr>
<td>EF</td>
<td>-2</td>
<td>1</td>
<td>4</td>
<td>-2</td>
<td>-3</td>
<td>-2</td>
<td>-8</td>
<td>-7</td>
<td>-8</td>
</tr>
<tr>
<td>MK</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Mean</td>
<td>1.11</td>
<td>2.67</td>
<td>3.33</td>
<td>2.00</td>
<td>5.11</td>
<td>2.11</td>
<td>4.11</td>
<td>6.33</td>
<td>15.00</td>
</tr>
<tr>
<td>SD</td>
<td>1.54</td>
<td>3.87</td>
<td>2.35</td>
<td>3.12</td>
<td>3.18</td>
<td>2.09</td>
<td>3.79</td>
<td>4.09</td>
<td>8.08</td>
</tr>
<tr>
<td>Min</td>
<td>-2</td>
<td>-12</td>
<td>-7</td>
<td>-10</td>
<td>-6</td>
<td>-4</td>
<td>-8</td>
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<td>-26</td>
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<tr>
<td>Max</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>10</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>-3</td>
</tr>
</tbody>
</table>

Negative values indicate received best-fit insertion gain was less than target insertion gain. Absolute values were used to compute means and standard deviations.

out the frequency range with the exception of 4000 and 6000 Hz where target gain could not be realized. However, mean differences and standard deviations were generally less when compared with the coupler differences in Table 2. That is, target insertion gain values were more closely approximated following hearing aid adjustment. Although adjustment of the hearing aids reduced difference values, many individual differences remain high even within the restricted range of 250 Hz through 3000 Hz. Sixteen of the differences or 25 percent were equal to or greater than 5 dB. The minimum tolerance for error would have to be ±12 dB within this restricted frequency range.

In order to more fully appreciate the significance of these deviations from target insertion gain, three of the most common prescription formulae were utilized in calculating target insertion gain for the mean audiogram values in Figure 1. Differences in prescribed target insertion gain are shown in Figure 2. The revised NAL formula values were equated to zero with the Berger formula (Berger, 1976) and POGO formula (McCandless and Lyregaard, 1983) difference values plotted accordingly. All plotted values were positive indicating the POGO and Berger formulae provide for greater target gain than the revised NAL. Target insertion gain differences as calculated with POGO are minimal except at the very high frequencies. Although the Berger formula prescribes significantly greater gain in the extremely low and mid frequencies compared to the revised NAL, an adjustment of hearing aid volume control would produce an insertion response that would minimize the differences.

Postfitting Evaluation

Each subject wore her or his hearing aid(s) for a minimum of 4 weeks and a maximum of 6 weeks before returning to the clinic to obtain preferred gain and postfitting HHI-E responses. Each subject was asked if the hearing aid volume control was adjusted to their typical daily wear setting and all subjects responded positively. The hearing aid was then removed without disturbing the volume control and evaluated in the hearing aid test box. The 2 cm³ coupler preferred gain was then compared with the prescribed 2 cm³ coupler target gain less any reserve gain. Difference values are listed in Table 4. Subjects' preference for more or less...
gain than prescribed was random at frequencies below 750 Hz. The indication of a preference for much less gain at 6000 Hz and to some extent at 4000 Hz is erroneous in that it was not technically feasible to obtain a close approximation of target insertion gain at these frequencies. It is well known that for analog circuitry, the typical frequency response will show the greatest amount of gain in the 1000 Hz to 3000 Hz range. Thus as shown in the table, the preference for an average of approximately 7 dB less gain than prescribed within this frequency range is of importance.

The HHI-E contains a list of 25 questions divided into two parts; a 12-question social subscale and a 13-question emotional subscale (Ventry and Weinstein, 1982; Weinstein et al., 1986). It has recently been demonstrated to be a useful tool in measuring hearing aid benefit (Newman and Weinstein, 1988). Pre- and postfitting scores for each subject in this study are listed in Table 5. Scores indicate that prior to the hearing aid fitting, all subjects individually and as a group perceived themselves as hearing handicapped. Based on a total possible score of 100, the subject group can be categorized as having mild to moderate hearing handicaps. Perceived handicap was slightly higher in response to questions regarding social versus emotional content. It is obvious that a very significant reduction in perceived handicap occurred for the entire group following the hearing aid trial period. In fact, scores were reduced to the extent that very little room for improvement remained.

**DISCUSSION**

The fact that three of the nine hearing aids had SSPL90 values as much as 9 dB greater...
than what was ordered was of some concern. Of particular interest was the aid received without a trimpot, which eliminated our lowering the maximum power output below the subject's previously obtained discomfort level. Given the limitations of analog circuitry, the manufacturer provided us with as close an electroacoustic match to what we prescribed as possible. It is well known that ordering an SSPL90 trimpot is no guarantee of receiving one because space is so limited within the hearing aid shell. Also, a desire for high gain but low maximum power output is technically incompatible. For the hearing aid in this study, the problem was of the former type. However, the subject had no complaint of discomfort during the fitting nor following the hearing aid trial period and therefore, the aid did not have to be sent back to the manufacturer to be altered. Although in this instance the trial period did not end in hearing aid rejection, it would appear important for us to consider whether we should routinely insist on some form of output limiting even at the expense of cosmetic appeal or target gain, to allow us flexibility of insuring that an aid's output will not exceed a patient's discomfort level.

In a follow-up to the Bratt et al (1987) study, Bratt and Sammeth (1991) were able to decrease the required tolerance for received all-in-the-ear aids to match the REIG as prescribed by the revised NAL formula. By using real ear measurements and adjustment of hearing aid venting and trimpots, they were able to reduce the tolerance from ±19 dB to ±15 dB. That is, in order to accept 90 percent of the hearing aids from the manufacturer, a tolerance of ±15 dB between 250 Hz and 4000 Hz was necessary. In order to accept 100 percent of their aids however, a tolerance of approximately ±20 dB was needed.

Bratt and Sammeth (1991) chose the traditional method of allowing the manufacturer to use matrix fitting to approximate an electroacoustic match to prescribed target gain. In the present study, the option to direct the manufacturer to custom build the hearing aid circuitry was successful in further reducing the required tolerance. To accept all of the aids in this study, it would require a tolerance of ±12 dB between 250 Hz and 4000 Hz. Tone trimpots and venting allowed for a relatively close match between target insertion gain and best-fit insertion gain in the frequencies below 1000 Hz. Volume control adjustment further reduced differences in insertion gain at 2000 Hz and 3000 Hz. By increasing the volume, one could compensate for the lack of gain at 4000 Hz only to increase the gain and therefore the error at 2000 Hz and 3000 Hz.

It would appear that analog circuitry in an optimal arrangement can provide no better than a ±12 dB electroacoustic match to prescribed target gain. Furthermore, given the relatively small differences in prescribed gain by various prescriptive formulae, perceived benefit of one formula over another may be a moot point (Humes, 1986; Sullivan et al, 1988; Gerling, 1990; Humes and Hackett, 1990; Bratt and Sammeth, 1991). Certainly as the more flexible and sophisticated circuitry that is incorporated in hybrid and digital aids becomes more readily available, studies comparing the perceived benefit of prescriptive formulae become more feasible as a result of the increased precision in matching target gain.

Of greater importance than one's choice of prescriptive formula is the determination of whether or not the formula provides amplification that maximizes a patient's satisfaction and communicative ability. Comparing prescribed gain with a patient's preferred gain is one way to approach patient satisfaction. Ideally the prescribed and preferred gain are equivalent if for no other reason than to increase patient confidence in your adjusting the hearing aid to the target insertion gain during the fitting. More importantly it becomes a factor in increasing your own confidence in having chosen a formula that best approximates your patient's needs. In the present study, preferred gain averaged 7 dB less than prescribed gain in the frequency range of 1000 Hz through 3000 Hz using the revised NAL formula. All but one subject preferred less gain than prescribed.

In contrast, Byrne and Cotton (1988) found near complete agreement for the three frequency average (500, 1000, and 2000 Hz) prescribed and preferred gain using the revised NAL formula. Recently, Leijon et al (1990) also used the revised NAL formula to compare prescribed and preferred gain and concluded that the formula overestimates average preferred gain by 5 to 10 dB at 1000 Hz through 2000 Hz. The difficulty of predicting preferred gain based upon hearing thresholds is that preferred listening levels can vary widely among patients with similar hearing loss (Brooks, 1973; Martin, 1973). Thus, prescribing the same gain for all individuals simply because they have the same hearing thresholds will result in inaccuracies of too little as well as too much gain.
However, this study found an almost unanimous desire for less gain than prescribed, which is most consistent with the findings of Leijon et al. (1990).

The ultimate goal of fitting amplification is to make optimal use of a patient's residual hearing and thus facilitate everyday communication. Achieving the prescribed target gain via formula fitting is an excellent first step. However, this study found an almost unanimous desire for less gain than prescribed, which is most consistent with the findings of Leijon et al. (1990).

The HHI-E has been shown to have excellent internal consistency and high test-retest reliability (Ventry and Weinstein, 1982; Weinstein et al., 1986). The questionnaire has also shown use as a measure of hearing aid benefit (Newman and Weinstein, 1988). The perceived benefit obtained by the subjects in this study would testify to the high degree of fitting success regardless of the apparently large tolerance required when using the revised NAL with analog circuitry and subjects' preference for lower gain than prescribed. Although it was not the intent of this study to compare HHI-E results across subjects when fit by different formulae, further significant improvement would appear difficult to achieve. Use of a questionnaire such as that suggested by Cox and Gilmore (1990) and Cox et al. (1991) may be of greater value as a research tool for determining hearing aid benefit because of its more analytic approach. Such an approach should provide more detailed indicators of deficit areas and help us to further differentiate among perceived benefits of any particular hearing aid fitting philosophy. Certainly a greater research effort is warranted in this area.

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REFERENCES


Gerling JI. (1990) Prescriptive Amplification Fitting: Fact or Fantasy. Paper presented at the ASHA annual convention, Seattle, WA.


