Fitting Hearing Aids to Adults Using Prescriptive Methods: An Evidence-Based Review of Effectiveness

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Abstract

The use of a prescriptive fitting approach for hearing aid selection has been a common practice for the past 60–70 years. While there are prescriptive approaches that have been validated, in recent years it has become popular to deviate from these validated methods and use manufacturers’ proprietary algorithms, which in many cases are significantly different. This research review was designed to examine if there was evidence supporting the use of specific gain requirements for hearing aid fitting. Specifically, the question that was asked was “Are there real-world outcome measures from adult patients that show a preference for the gain prescribed by a specific prescriptive fitting procedure?” Inclusion criteria were as follows: adult subjects, consistent technology (e.g., different prescriptive methods compared using same hearing aids), real-ear verification of gain, and real-world outcome measures. For this review, in addition to subjective responses, preferred use gain was considered a real-world outcome measure. The National Acoustic Laboratories’ revised (NAL-R), revised for severe/profound (NAL-RP), and the National Acoustic Laboratories—Non-Linear 1 (NAL-NL1) prescriptive methods were used as a common reference, as they have been the most commonly studied methods with adults.

Eleven studies were identified that met the inclusion criteria. Eight of the studies supported gain similar to that prescribed by the NAL-R or NAL-RP methods; three studies supported prescribed gain less than the NAL-R or NAL-RP. There was no evidence that gain greater than that prescribed by the NAL methods should be used. The level of evidence was moderate, as the supporting studies were either Level 2 or Level 4, and the statistical power of the studies was low.

Key Words: Evidence, formula, gain, hearing aid, NAL, outcome, prescription, real world

Abbreviations: AGCo = automatic gain control-output; BTE = behind the ear; CAMEQ = Cambridge loudness equalization method; CAMREST = Cambridge loudness restoration method; CORFIG = coupler response for flat insertion gain; DSL = Desired Sensation Level; NAL-R = National Acoustic Laboratories’ revised; NAL-RP = National Acoustic Laboratories’ revised profound; NAL-NL1 = National Acoustic Laboratories—Non-Linear 1; REIG = real ear insertion gain; rms = root mean square; VC = volume control; VIOLA = Visual Input/Output Locator Algorithm; WDRC = wide dynamic range compression

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In 1996, James Jerger titled his editorial in the December issue of JAAA, “Hearing Aid Fitting: Quo Vadis?” This question was linked to the lead article of the issue, written by Denis Byrne (1996). In his article, Byrne expressed concern that in the future, rather than using validated prescriptive methods, hearing aids would be fitted using manufacturer-specific proprietary formulae for calculating amplification requirements. He states:

The scenario described raises concerns, both scientific and philosophical. Scientifically, the concern is that amplification may become prescribed by a wide variety of proprietary formulae of which few, if any, are validated by published research. A possible philosophical problem is that control of the fitting process is taken away from the fitter, who is responsible for the care of the client. [1996, p. 378]

Unfortunately, the concerns of Byrne (1996) have materialized. Validated prescriptive fitting approaches currently often are not used or verified when fitting hearing aids for adults. Although it is poorly documented, it is common knowledge that most audiologists program the gain and output of hearing aids using a manufacturer’s “first-fit” algorithm. In some cases, this algorithm is the manufacturer’s modification of a validated procedure (e.g., National Acoustic Laboratories’—Non-Linear 1 [NAL-NL1] or Desired Sensation Level [DSL] 4.1), although often it is a proprietary algorithm.
that differs significantly from standard methods. Keidser et al (2003), for example, in a study examining the recommended algorithms of five different major manufacturers, show that it is common for prescribed gain to differ by 10 dB or more from the NAL-NL1 targets in the high frequencies for average-level input signals. Killion (2004) recently examined the gain for 16 modern instruments programmed to proprietary first fits from different manufacturers. His results show that average programmed gain was much less than normally prescribed by validated procedures; reduced to the extent that the aided Speech Intelligibility Index (SII) usually fell below 50% for a 55 dB SPL input for simulated mild-to-moderate hearing losses.

It is sometimes suggested that the fitting algorithms of today’s products need to be different, because of the instrument-specific multichannel digital processing of the speech signal. To account for this variable, Bentler (2004) recorded the 2-cc coupler response of hearing aids using a one-minute male real-speech input (long-term 65 dB SPL input). She examined the default algorithm of the premier product from six leading hearing aid manufacturers; the hearing aids were programmed for a flat 50 dB HL hearing loss. The findings are shown in Figure 1. Observe that, in general, most of the algorithms are quite different than the gain prescribed by the NAL-NL1, and that prescribed gain for the key frequencies of 1500 Hz to 3000 Hz varies by as much as 15 dB among products. Consider also that these are 2-cc coupler data. If we apply average behind-the-ear (BTE) CORFIGs (coupler response for flat insertion gain) to predict real-ear insertion gain (REIG), the values shown here would be reduced by 5–10 dB for 1500 Hz to 4000 Hz; several instruments would be providing less than 10 dB of real-ear gain for much of the speech range. It is difficult to reconcile these prescriptive philosophies with what we know about audibility and speech intelligibility.

To add further to the uncertainty of today’s fitting, Hawkins and Cook (2003) report that the prescriptive gain displayed in the manufacturer’s software may be quite different than what is present in the real ear. While it is expected that differences would occur between simulated REIG and measured REIG due to individual CORFIG correction variations, these authors show that there is a distinct pattern of deviation; an average reduction of high-frequency gain of 5–10 dB. That is, even if an audiologist selected a validated procedure such as the NAL-NL1, and the computer display showed an excellent match to target, it is possible if not probable that the real-ear gain above 2000 Hz will fall well below this prescriptive target.

This leads us to the point that to actually use a prescriptive approach or, rather, for the patient to use a prescriptive approach, the audiologist must ensure that the prescriptive targets are met in the patient’s ear canal. Even if coupler values are known to match the desired target gain (e.g., measured by the audiologist), it is difficult to predict real-ear gain from coupler gain on an individual

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**Figure 1.** Display of 2-cc coupler gain for the “first fit” of the premier product from six of the leading hearing aid manufacturers. Hearing aids programmed to a flat 50 dB HL hearing loss. Input was one-minute segment of real speech of a male talker; average rms of 65 dB SPL NAL-NL1 target for speech at 65 dB input shown for reference. From Bentler, 2004, used with permission.
basis due to the variability of the components of the CORFIG: the real-ear unaided gain (REUG) (Valente et al, 1991), the real-ear coupler difference (RECD) (Saunders and Morgan, 2003), and the microphone location effects (MLE) (Fikret-Pasa and Revit, 1992).

Real-ear verification of prescriptive targets, however, even when hearing aids have several special digital features, can be accomplished through the use of probe-microphone measures (e.g., Mueller, 2001; Dillon and Keidser, 2003). And, in fact, audiologists using a proprietary algorithm for “first fit” could later adjust the gain of the instrument to match established real-ear targets. Surveys consistently show, however, that the majority of audiologists do not routinely use probe-microphone measurements in the fitting of hearing aids (Mueller, 2003). This final point is the basis of my earlier statement that validated prescriptive methods are not commonly used. Could this simply be because there is not supporting evidence for their use?

The concept of “selective amplification” dates back to the early days of vacuum tube hearing aids. Watson and Tolan, for example, discuss prescriptive fitting methods in their 1949 textbook on hearing instruments. Over the years, there have been 20–30 different published prescriptive formulae. Some named after people (e.g., Berger, Bragg, Libby, Lybarger, Shapiro, Victoreen) and others named after places (e.g., Cambridge, Central Institute for the Deaf [CID], Memphis State University [MSU], NAL). The name of a few attempt to describe what the method does (e.g., DSL, Prescription of Gain and Output [POGO], Visual Input/Output Locator Algorithm [VIOLA]), and one method simply is named after a figure (FIG6). Today, however, in the United States, two methods have emerged as the defaults for clinical use: the NAL-NL1 and the DSL4.1.

Inherent in the use of prescriptive fitting methods is the belief that appropriate gain and output can be selected for the average patient based on that patient’s audiometric characteristics. Different fitting methods, however, may have different fitting goals. The desired outcome might be geared toward optimizing audibility, loudness restoration, loudness equalization, speech intelligibility or listening comfort, or some combination of these factors.

In conducting an evidence-based review of the effectiveness of prescriptive fitting methods for adults, a reasonable first question would be: Is there evidence supporting the use of a commonly used method (such as the NAL-NL1) versus no prescriptive method? While this seems like a good starting point for a literature review, it is difficult to define the meaning of “no prescription.” We would all agree that for someone with a 60 dB HL hearing loss, 0 dB gain is too little, and 100 dB of gain is too much. Once we begin to narrow the range of desired gain, however, we are using a prescriptive fitting approach. No research has been published that has included a fitting where random gain values, differing by large amounts, have been arbitrarily assigned to different adjacent frequencies. With modern technology, it is becoming easier to implement a fitting method where the subject selects all frequency-specific gain parameters. If the range of selection parameters were not influenced by the past knowledge of the researcher, then this could be considered a “no prescription” approach.

Because all researchers have a general knowledge of what gain values would obviously be too little or too much, published research with prescriptive methods has focused on finding a small range of optimum gain values, contained within the boundaries of a larger range of reasonable gain values. This review, therefore, will be limited to the range of prescriptive values that commonly occur among methods, or that are achievable when experimental subjects are provided with control of the hearing aid's overall gain.

Historically, research studying prescriptive fitting methods has been conducted in laboratory settings. This allows the researcher to examine the effects of making relatively small changes in the amount of gain and the slope of the gain function, often using a form of “master hearing aid.” Testing usually consists of speech intelligibility measures in quiet and in noise, paired comparisons, and the patient’s judgments of quality, loudness, and other factors. In recent years, however, there has been a trend to rely on real-world outcomes, and that will be the focus of this review.

Research that has examined the effectiveness of prescriptive fitting methods using real-world outcomes can be grouped into two general areas. The design of several studies was to fit a group of individuals according to a specific prescriptive method,
allow the subjects to control the overall gain of the instruments in their everyday activities (or the experimenter adjusts it based on the subject’s comments), and then assess “use gain” at a later date. If use gain is similar to the original programmed gain, the prescriptive method utilized would be considered appropriate, or at the least acceptable. An alternative method is to provide the subjects with two or more different prescriptive methods for trial in the real world. That is, the subjects use hearing aids programmed with different fitting rationales (or variations of the same rationale), and they select the method that was the best, based on some criteria provided by the investigators. This can be conducted in a crossover design, or using hearing aids with multiple memories. In this case, the prescriptive method that is the “winner” is considered the most appropriate. The present review includes both types of prescriptive studies if they met all other inclusion requirements.

METHODS

Inclusion and Exclusion Criteria

The general guidelines for an evidence-based review that are outlined by Cox in this issue of JAAA, including the six levels of evidence that she reviews, were followed. The question that was formulated was this: “Are there real-world outcome measures from adult patients that show a preference for the gain prescribed by a specific prescriptive fitting procedure?” For the evaluation of clinical effectiveness, studies were included in the review if they met the following criteria:

- Used either a randomized control, randomized crossover, a nonrandomized intervention (aka quasi-experimental), or a nonintervention descriptive research design
- Used adult subjects with hearing impairments
- Verified that prescribed targets were met, or met as well as possible with probe-microphone measurements
- Used consistent technology for comparisons
- Involved the use of hearing aids in the real world (outside of simulated laboratory conditions)
- Used a measure of use gain, a self-report of prescriptive gain preference, or real-world benefit

The decision to review only articles from 1985 forward was not arbitrary. Articles prior to 1985 did not use probe-microphone measurements to verify that subjects actually were fitted with a given prescriptive method. Even since then, several studies of prescriptive fitting approaches have been conducted in which real-ear gain was not measured. If the goal of the research is to examine differences among different formulae, then 2-cc coupler information is a reliable and sufficient metric. However, if we are to draw real-world conclusions concerning what amount of gain is preferred by hearing aid users, or if one method is preferred over another, then knowing the real-ear gain that actually was present during the clinical field trial is essential. The 1985 date also is important regarding the relevance of the prescriptive methods reviewed. The NAL-R (National Acoustic Laboratories’ revised) method was introduced around this time (Byrne and Dillon, 1986); for the most part, prescriptive fitting methods used prior to 1985 are not used today.

Another inclusion item concerns the consistency of the technology used in the research. That is, did the subjects use the same hearing aids when different prescriptive methods were compared? An example of an article that was excluded because of this was the work of Humes et al, 1999, which at first glance might appear to be research supporting the gain prescribed by DSL[i/o] over that prescribed by the NAL-R. As pointed out by the authors, however, this would be an overinterpretation of the findings. While real-world outcome measures did favor the hearing aids programmed with the DSL[i/o] algorithm, these new hearing aids employed wide dynamic-range compression (WDRC). They were compared to the patient’s old linear hearing aids, which happened to be programmed to the prescribed gain of the NAL-R. For reasons such as this, research was included only when the same technology was used for all comparisons.

Search Strategy

The search strategy was aimed initially to identify all articles that have studied the
Prescriptive fitting evidence for adults

Specific key words that were used included “hearing aids,” “prescriptive,” “fitting,” “formula,” “gain,” as well as the names and acronyms of popular fitting methods. The databases searched included: PubMed, MEDLINE, CINAHL, and EMBASE. All searches were conducted in January 2005. In addition to the computerized searches, the reference lists of the articles that met the inclusion criteria were reviewed, as well as key review articles on the topic. Researchers in the area also were contacted to obtain their opinions regarding articles that would meet the inclusion criteria. In three cases, authors were contacted to clarify experimental details so that an inclusion/exclusion decision could be made.

Figure 2 reviews the flow of the search process. Initially, 136 articles were identified as being potentially relevant. Primarily through abstract review, 94 articles were eliminated, leaving 42 articles for further analysis. Finally, 11 articles were selected that met all inclusion criteria and are summarized in this review. At this final level, the primary reason for exclusion was that the research did not include a real-ear measurement of gain or that there was not a real-world outcome measure.
Data Extraction

Each article was reviewed, with specific attention to the following areas: design, study population, research question, and outcome measure used. If use gain was provided, these values were compared to NAL-RP (National Acoustic Laboratories’ revised profound) targets for the mean audiogram. The outcome of each study was rated regarding how the resulting preferred prescriptive gain compared to NAL-RP prescribed targets. Three different ratings were applied:

>NAL = Preferred gain was greater than NAL targets
~NAL = Preferred gain was similar to NAL targets
<NAL = Preferred gain was less than NAL targets

There are several reasons why the target gain of the NAL-RP procedure was chosen as the reference: it is the most used prescriptive method, it is the most researched method, and the gain-for-average prescription has not changed significantly in the revisions that have occurred over the past 20 years. There are four iterations of the NAL family of prescriptive methods:

- Original NAL (Byrne and Tonnison, 1976): Not used extensively in the United States; typically not referred to as the “NAL method” in the United States
- NAL-R (R = Revised) (Byrne and Dillon, 1986): A revision of the original Byrne and Tonnison (1976) formula. The most researched prescriptive fitting approach, and rapidly became the most popular fitting method in the United States in the late 1980s and 1990s. Was implemented in hearing fitting software and by most manufacturers of probe-microphone equipment.
- NAL-RP (P = Profound) (Byrne et al, 1990): A modification of the NAL-R method for people with severe-to-profound hearing loss. Prescriptive targets are the same as NAL-R prescribed gain when loss is mild to moderate.
- NAL-NL1 (Dillon et al, 1999; Byrne et al, 2001): A revision of NAL-RP method including prescribed gain for a wide range of inputs. Prescribed gain for average inputs, however, is essentially the same as for the NAL-RP.

Not all the studies in this review used the same version of the NAL prescriptive method for programming the hearing aids or for making comparisons. However, because the gain-for-average prescription has not changed significantly since the introduction of the NAL-R, and the focus of the research reviewed was gain-for-average inputs, it is reasonable to generalize the results across the different investigations. While an attempt has been made to calibrate this review to gain-for-average inputs, because patients used the hearing aids in the real world, it certainly is possible that the preferred gain outcome in some studies was driven by gain for soft and/or loud inputs.

Many of the studies did not program the hearing aids to the recommended gain of one of the NAL methods; compare their results to the recommended gain of one of the NAL methods, or report gain for a 65 dB SPL input. When this was the case, the mean audiogram for the subjects, including whatever hearing aid specific information was known (e.g., BTE, two channel, bilateral fitting, etc.), was entered into the NAL-NL1 fitting software to calculate average REIG (or 2-cc coupler) targets for the study group. It is recognized that calculating mean gain from a mean audiogram may not give the same values as calculating each individual’s target gain and then obtaining a mean, but the differences should be small. These derived targets from the NAL-NL1 software were then compared to the measured values reported in the study for the input nearest 65 dB SPL, which often was 55 dB SPL. It was assumed that if the match was close at 55 dB SPL (i.e., root mean square [rms] average difference of 5 dB or less for the frequencies 500 to 4000 Hz), then the match for 65 dB SPL input also would be reasonably close, as most investigators used a compression ratio similar to that prescribed by the NAL-NL1. If this comparison resulted in a close match, a “~NAL-RP” rating was assigned.

As mentioned, an rms error of 5 dB for prescribed overall gain across key frequencies was considered the cut-off value for the same/different comparison rating with the NAL-RP targets. In research with prescriptive methods, it is common to program the hearing aids so that the rms fitting error across frequencies is no larger than 2–3 dB (e.g., Byrne and Cotton, 1988, Moore et al, 2001). Cox and Alexander (1990) found, however,
that differences among prescriptions were preserved if the rms error for the match to target was 5 dB or less. Baumfield and Dillon (2001) found that benefit and satisfaction was significantly reduced when the rms error (at 1000, 2000, and 4000 Hz) was 6 dB or more. The 5 dB rms error criterion was based on the above findings.

Several studies used or referred to the prescriptive methods developed at Cambridge. To summarize, the Cambridge method for loudness equalization is the CAMEQ (Cambridge loudness equalization method) (Moore et al, 1999). The Cambridge method for loudness restoration is the CAMREST (Cambridge loudness restoration method) (Moore, 2000). While derived somewhat differently, the prescribed gain for average inputs obtained with CAMEQ is similar to that prescribed by the NAL-RP.

RESULTS

Selection Flow

Figure 2 shows the number of articles that were included or rejected and the reasons for rejection. The articles selected included four that used only use gain as the outcome measure, and three that only used a self-report measure (e.g., selecting a “favorite” response after extended field trial). One of the later studies (Baumfield and Dillon, 2001) did not compare different responses but, rather, compared insertion gain match-to-target to the relative benefit observed on self-assessment scales. Four articles used a combination of use gain, and a self-report measure of benefit or satisfaction.

Study Characteristics

The details of each study are summarized in Table 1. One study utilized a randomized control trial (Level 2); three studies used a randomized crossover (Level 2); three studies used a simultaneous crossover design (Level 2); and four studies were descriptive (the descriptive studies could be classified as “cross sectional survey”—see Cox in this issue for review). The simultaneous crossover design used in three studies was not described by Cox (this issue), as it is not considered a standard research design and is somewhat unique to hearing aid research. In other fields, a randomized crossover design often is used, where subjects experience different treatments at different times. For some studies reviewed in Table 1, however, different prescriptive gain was programmed for different memories of multimemory hearing aids, and the subjects could access the different memories at any time during the field trial. “Crossover” could occur several times in a day. Hence, the labeling of this design “simultaneous crossover.”

The lengths of the field trials were quite variable, ranging from two weeks to one year. The hearing aid technology employed also was variable. Prior to 2001, the studies primarily utilized linear hearing aids. Since that time, nearly all studies have used WDRC instruments. Table 1 does not identify whether the subjects were experienced or new users; for most studies they were both. Most research has shown that there is little or no difference for preferred gain between new or experienced users (e.g., Bentler et al, 1993; Kuk and Lau, 1996; Arlinger et al, 2000). Marriage et al (2004), in research cited in Table 1, did find that new users preferred less gain than experienced users, but only around 3 dB.

Study Quality

All studies that compared different prescriptive fittings employed blinding to the subjects. Randomization procedures were applied whenever appropriate. The studies that used statistical analysis of the data did not report a power calculation. Of the nine studies that used a self-report inventory, five of the studies used an inventory that has been validated.

Findings

As shown in Table 1, eight of the 11 studies support the use of prescriptive gain that is similar to that prescribed by the NAL-RP procedure. The three studies involving the Cambridge methods showed use gain for the CAMEQ procedure (after subject-driven adjustments) that was very close to NAL-NL1 prescribed targets. The CAMREST use gain and the DSL use gain (after subject-driven adjustments) were very similar to the CAMEQ. No difference among procedures was observed for real-world benefit, and therefore a “~NAL-RP” rating was given to
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<td>Moore et al (2001)</td>
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<td>Comparison of CAMEQ, CAMREST, and DSL Adjustments made to make fitting “acceptable” Hearing aids = WDRC</td>
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these studies. Three studies supported less gain than that prescribed by the NAL-RP, although the Smeds (2004) use gain findings appear to fall very close to the 5 dB rms criterion. The other two studies with the “<NAL” rating report use gain that is clearly significantly below NAL-RP prescribed values. Of the eight studies favoring gain similar to the NAL-RP, five are Level 2 (randomized crossover or simultaneous crossover) and three are Level 4 (descriptive) (see Cox in this issue for review). This allows for a moderately strong recommendation for the use of prescriptive fitting targets similar to the NAL-RP prescription.

**DISCUSSION**

In clinical practice today, there appears to be a growing trend to use proprietary algorithms to fit hearing aids, rather than the prescriptive fitting methods that have been validated through research. As pointed out by Byrne (1996), this approach takes the fitting process out of the hands of the audiologist, the person responsible for the patient's care and treatment. The purpose of this review was to summarize the evidence available relating prescriptive fitting approaches to real-world benefit and satisfaction, and to determine if the evidence tends to support, in general, a specific rationale for selecting hearing aid gain.

As stated, studies were given a “~NAL-RP” if the resulting preferred gain met the <5 dB rms average error criterion for prescribed overall gain. To some extent, this ignores a critical part of the prescription, the slope of frequency-specific gain function. That is, for a person with a flat hearing loss, one method could prescribe a downward sloping gain function, and another method could prescribe an upward sloping gain function, yet overall average rms difference could be within 5 dB.

The slope of the gain function can be more critical for the patient than actual overall gain, as overall gain can be altered with a volume control, while the slope cannot. While slope was not shown as a separate category in Table 1, in all the studies given a “~NAL-RP” rating, the slope of the gain function was very similar to the NAL-RP. In fact, in three studies that initially used a slope different than the NAL-RP, patient-driven adjustments made the slope of these fittings more similar to the slope of NAL-RP. In one of the studies cited obtaining a “<NAL-RP” rating (Smeds, 2004), subjects compared the NormLoudn method to the LessLoudn prescribed gain. The NormLoudn is essentially the CAMEQ, which has a gain-for-average-inputs slope that is very similar to the NAL-RP. The LessLoudn has a slope that is essentially identical to the NormLoudn.

Although there appears to be a general consensus supporting the gain recommended by the NAL-RP (or procedures recommending gain similar to the NAL-RP), it is worthwhile to discuss briefly one extreme finding summarized in Table 1. The research supporting the use of the least amount of gain is that of Cunningham et al (2001). These authors’ initially fitted two groups of patients using the DSL method and then modified the gain at the time of the fitting based on the aided speech verification procedure of the Independent Hearing Aid Fitting Forum (IHAFF) (see Mueller, 1999, for review). The resulting REIG was significantly lower than prescribed by the DSL, falling about 2–4 dB below the NAL-RP prescribed gain. During the field trial, gain for the treatment group was altered according to the subjects’ request on five monthly postfitting visits (no gain changes were allowed for the control group). At the end of five weeks, the resulting average gain (70 dB SPL input) for the treatment group was only 3 dB (compared to about 10 dB for the control group). The hearing aids employed WDRC, so we would predict that the treatment group had about 5 dB average gain for a 65 dB input (group mean PTA of 26 dB at 500 Hz sloping to 58 at 4000 Hz). This clearly is the lowest preferred gain observed in any study for individuals with this degree of hearing loss. It seems unlikely that this minimal amount of gain would have maximized intelligibility; however, the APHAB results for this group were not significantly different than for the control group in this low-power study.

Another study that supports the use of gain significantly less than prescribed by NAL-RP is the work of Humes et al (2000). It is not included on Table 1 because it did not meet the inclusion requirement of verifying gain in the real ear. It does merit discussion, however, as it was well designed and included a large number of subjects (n = 55). These authors monitored use gain via 2-cc coupler measures over one year. The initial fit to
NAL-R also was via 2-cc coupler, but if we assume that these subjects, as a group, had average CORFIGs, then the findings are relevant to our discussion here. Humes et al (1990; see Table 1) observed use gain that was an average of 6–9 dB lower than that prescribed by the NAL-R, results very similar to those of Leijon et al (1990), one of the few other studies that has reported preferred use gain less than that recommended by NAL-RP. Of interest, the subjects in the Humes et al (2000) research were fitted with hearing aids employing linear gain. In a similar coupler study by Stelmachowicz et al (1998), using hearing aids with WDRC, use gain was found to be very similar (for both overall average gain and slope) to that recommended by the NAL-NL1.

In all of the studies reviewed in Table 1, the authors reported that the subjects initially were fitted according to a given prescriptive method, or in some cases, two or three different methods. It is important to question, however, how close to target REIG does the fitting have to be to be considered a “fit to target?” In most of the more recent research (e.g., the work from the Cambridge laboratory), there has been a reasonably close match to target through 4000 Hz. In some of the earlier studies, however, the mean REIG mismatch to target at 3000 Hz and above has been 5–10 dB; one could argue that as a group these subjects were not really fitted using the NAL-RP method. In some of the studies reviewed, the authors simply state, “hearing aids were fitted according to the NAL-RP prescriptive method,” and mean REIGs were not reported. In three studies, the subjects had VCs, and the outcome measure was “use gain.” It is important to know how use gain was determined when the laboratory real-ear measures were conducted. Was it based on where the VC was set when the patient walked in the door, or the patient’s memory of where he or she usually used the VC, or on a return visit did the patient listen to average speech in the laboratory and adjust the VC until a preferred listening level was reached?

Related to VC settings is the issue of acclimatization. To state the obvious, subjects cannot acclimatize to a given amplified signal if they do not experience that signal for an extended period of time. In few if any of the studies reported here did the subjects have extended hearing aid experience prior to experimental testing with gain that exceeded NAL-RP targets. In some studies, gain for a given prescriptive method was adjusted (especially the high frequencies) prior to or during the field test to make the amplified signal more “acceptable” for the patient, or to eliminate acoustic feedback, which often served to make the “different method” more like NAL-RP. The conclusions drawn in this review are largely based on the subjects’ preferred gain, with the assumption that what they preferred probably is best for them.

Regarding technology, several studies that met the inclusion criteria utilized linear hearing aids for the real-world listening experience. Rarely are linear fittings used today. Nearly all of today’s products employ multichannel WDRC, with AGCo (automatic gain control-output) for compression limiting. Does technology influence real-world preferred gain? If the study allowed the subjects to adjust gain (and used the resulting gain settings as the outcome measure), one could argue that the subjects would perhaps use more gain with newer technology, as there is less chance that loud sounds would be too loud, a common reason why gain is turned down. On the other hand, we know that WDRC usually results in more gain for soft sounds (compared to linear amplification), and this might prompt subjects to use less gain, as many people are annoyed by hearing soft sounds, especially if they are not used to hearing them. Most patients fitted today have hearing aids employing digital noise reduction (DNR), and this often is the default setting for the primary program. Does DNR influence use gain? Most of the studies reviewed used hearing aids that did not have DNR; in other studies, it specifically was mentioned that DNR was turned off (e.g., Marriage et al, 2004, Smeds, 2004). And what about low-level expansion? This might prompt individuals using WDRC to use more gain, as the low-level annoying noises, at least in theory, would not be as annoying. No study mentions the use of expansion in the experimental hearing aids. Clearly, more research on this topic is needed, using subjects fitted with the technology and special features that are common in today’s hearing aids.

Finally, it is important to point out that the evidence presented here relates only to adults with mild-to-moderate hearing loss. It is probable that the severe-to-profound
hearing loss group has different gain requirements. And certainly, the evidence for prescriptive fittings for infants and children must be reviewed separately (see Palmer and Grimes, this issue). For example, Scollie et al. (2000) report that preferred listening levels for children are very similar to gain prescribed by the DSL targets and that on average the NAL-RP/NL1 methods recommended less gain than preferred.

In summary, based on the use-gain data and real-world subject preferences, there is evidence to support the conclusion that for average inputs, gain approximating that recommended by the NAL-RP procedure is most preferred by adult hearing aid wearers. Because of the limited number of studies and the low statistical power of these studies, it is not possible to make a strong recommendation. The available evidence, however, supports the following clinical procedure when fitting hearing aids to adults:

1. Conduct first-fit programming using (if possible) a method that prescribes gain-for-average input similar to that prescribed by the NAL-RP/NL1.
2. Verify the fitting using either REIG or REAR (real-ear aided response).
3. Use an authentic speechlike signal (or real speech) at an input 65 dB SPL.
4. Adjust gain/compression parameters until a match to NAL-RP target (or similar) within 2–3 dB, or at least within 5 dB, has been obtained at all key frequencies.

The following are qualifications of the available evidence:

- The evidence presented here only applies to adults with mild-to-moderately-severe sensorineural hearing loss.
- The supporting evidence is not limited to the NAL family of formulae. Other methods, including some proprietary algorithms, may prescribe similar gain values.
- Prescriptive methods that are similar to the NAL prescribed targets for average inputs may differ from the NAL-NL1 prescribed gain for soft or loud inputs.
- While gain for soft and/or loud inputs might have influenced preferred gain in many of the studies, the conclusions are only for gain-for-average level inputs.
- It is unlikely that many, if any, of the subjects used in these studies had experience prior to experimental testing using prescribed gain greater than recommended by the NAL-RP.
- Acclimatization to higher levels of overall gain, audibility at frequencies not previously amplified, or a different frequency-specific gain slope could alter the preferred gain outcome.

Several of the studies cited used technology that is not commonly used today. Even in the studies using “modern technology,” features such as digital noise reduction and low-level expansion were not implemented. It is not known if these features, which are common in today’s products, influence preference for overall gain levels. Given the programming flexibility of modern hearing aids, well-controlled Level 2 studies comparing different prescriptive gain strategies easily could be implemented.

There is a critical need for more high-quality research of this type with current devices.

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REFERENCES


