Fitting Hearing Aids Using Clinical Measures of Loudness Discomfort Levels: An Evidence-Based Review of Effectiveness

H. Gustav Mueller* 
Ruth A. Bentler†

Abstract
Clinical measurement of the loudness discomfort level (LDL) historically has been part of the hearing aid fitting procedure, and this clinical practice remains popular today. LDL measurements also are recommended in contemporary hearing aid fitting protocols. Yet, surveys show that many hearing aid users are dissatisfied with the loudness of their hearing aids. In this evidence-based review article, we evaluate the effectiveness of clinical LDL measurements. Specifically, we asked the question “Are the clinical measurements of LDL for adult patients predictive of aided acceptance and satisfaction of loudness for high inputs in the real world?” Nearly 200 articles were reviewed; three met the criteria set forth in this review. The evidence supported using unaided LDLs for selecting the maximum real-ear output of hearing aids. No study using aided LDLs or aided loudness verification met the criteria. The level of the evidence for the three articles using unaided LDLs was low; no higher than Level 4. The limited number of studies, the level of evidence, and the statistical power of the studies prevents us from making a strong recommendation concerning the clinical use of LDL measures. Additional research in this area, especially research employing randomized controlled trials would be a useful addition to this body of literature.

Key Words: Evidence, hearing aid, loudness, loudness discomfort, maximum output, output, OSPL90

Abbreviations: AGCI = automatic gain control-input; AGCo = automatic gain control-output; DSL = Desired Sensation Level; IHAFF = Independent Hearing Aid Fitting Forum; LDL = loudness discomfort level; NAL-NL1 = National Acoustic Laboratories’—Non-Linear 1; OSPL90 = output sound pressure level for 90 dB input; RECD = real-ear coupler difference; REDD = real-ear dial difference; RESR = real-ear saturation response; RETSPL = reference equivalent threshold in sound pressure level; TD = threshold of discomfort; UCL = uncomfortable level; UL = uncomfortable level; VIOLA = Visual Input/Output Locator Algorithm

Sumario
Las mediciones clínicas del nivel de molestia en la percepción subjetiva de la intensidad (LDL) ha sido históricamente parte del procedimiento de adaptación de un auxiliar auditivo, y esta práctica clínica sigue siendo popular hoy día. Las mediciones del LDL también son recomendadas en los protocolos contemporáneos de adaptación de auxiliares auditivos. Sin embargo, los estudios muestran que muchos usuarios de audífonos no están satisfechos con la sonoridad de sus auxiliares auditivos. En este artículo de revisión basado en evidencia evaluamos la efectividad de las mediciones clínicas del...
The measurement of loudness discomfort has long been a component of hearing aid selection and fitting. In one of the first texts written on the prescription and fitting of hearing aids, Watson and Tolan (1949) discuss the prefitting importance of establishing the range of comfortable listening (RCL), which they define as the difference between the measured most comfortable level and the loudness discomfort level (LDL).1 The seminal reports of both Carhart (1947) and Davis et al (1946) provided early guidance concerning the clinical measurement of aided loudness, and subsequent hearing aid adjustment if necessary.

Loudness discomfort measures also have been included as part of published hearing aid fitting protocols spanning the past 50 years. From the 1950s guidelines of the American Speech and Hearing Association to the Vanderbilt Protocol of 1990 (Hawkins et al, 1991), the 1994 Independent Hearing Aid Fitting Forum (IHAFF) protocol (Cox, 1995), and the most recent protocol for adults (Valente et al, 1998), some type of loudness measure has been recommended. For example, the Valente et al protocol states: “Thresholds of discomfort (TD) should be directly measured using frequency-specific stimuli when possible to accurately assess/adjust the appropriate output and/or compression characteristics of the hearing aids” (1998, p. 6).

Many prescriptive fitting methods also have used measured LDLS to prescribe the hearing aid’s maximum output. Hawkins et al (1992) reviewed six different procedures from the 1980s; four involved subject-specific measurements of LDL. Mueller and Hornsby (2002) reviewed four currently used prescriptive fitting approaches: Desired

---

**Palabras Clave:** Evidencia, auxiliar auditivo, intensidad subjetiva, incomodidad producida por la percepción subjetiva de la intensidad, salida máxima, salida, OSPL90

**Abreviaturas:** AGCI = ingreso del control automático de ganancia; AGCo = salida del control automático de ganancia; DSL = Nivel Deseado de Sensación; IHAFF = Foro Independiente de Adaptación de Auxiliares Auditivos; LDL = nivel de incomodidad por la percepción subjetiva de la intensidad; NAL-NL1 = Laboratorios Nacionales de Acústica – No Lineal 1; OSPL90 = nivel de presión sonora para 90 dB de entrada; RECD = diferencia del acoplador en oído-real; REDD = diferencia de dial en oído real; RESR = respuesta de saturación en oído real; RETSPL = umbral equivalente de referencia en nivel de presión sonora; TD = umbral de molestia; UCL = nivel de incomodidad; UL = nivel de incomodidad; VIOLA = Algoritmo del Localizador Visual de Ingreso/Salida
Sensation Level (DSL) v4.1a (Seewald et al., 1997), FIG6 for Windows v3.0 (Etymotic Research, 1996), National Acoustic Laboratories—Non-Linear 1 (NAL-NL1) v1.01 (Dillon et al., 1999), Visual Input/Output Locator Algorithm (VIOLA) for Windows v1.0 (University of Memphis Hearing Aid Research Laboratory, compact disc, 1999). Two of these, the DSL and VIOLA, utilize frequency-specific measured LDLs, although both also will predict LDLs from hearing threshold.

Currently, the majority of audiologists utilize a manufacturer-specific fitting method, and some of these proprietary approaches have incorporated in situ LDL measures (i.e., using the hearing aid to deliver the test signal) for selecting maximum output (see Mueller and Hornsby, 2002, for review). Nearly all major manufacturers also use the measured LDL (obtained via earphones) in their fitting software to adjust the Output Sound Pressure Level for a 90 dB input (OSPL90), usually by raising or lowering the automatic gain control-output (AGCo) kneepoint. This AGCo adjustment within the software may even occur when employing a prescriptive method such as the NAL-NL1, which does not utilize measured LDLs (Mueller, 2004).

Given this history, it is not surprising that the measurement of LDLs for the purpose of fitting hearing aids is popular among audiologists. In 2003, Mueller reported survey results showing that 61% of audiologists routinely conduct prefitting LDLs via earphones, and 44% routinely conduct aided LDL measures; only 19% of audiologists stated that they did not routinely conduct either. These findings are consistent with surveys from past years showing that at least 80% of audiologists conduct LDLs at some point in the hearing aid selection and fitting process (e.g., Mueller and Bright, 1994; Mueller and Strouse, 1995; Martin et al., 1998). While popularity of an audiologic test procedure does not equate to efficacy (Wiley et al., 1995), it seems reasonable to assume that most audiologists believe that LDL measurements are a useful component of a hearing aid fitting protocol.

**LDL Measurement Considerations**

Before reviewing the research evidence concerning the clinical measurement of loudness discomfort, it is important to first address three different areas that influence the relevance of the review.

**Interpatient Variation**

Do LDLs vary significantly among the range of patients who are fitted with hearing aids? If they do not, a generic hearing aid maximum power output (MPO) value simply could be selected for all patients. This question has been examined in several large scale studies (e.g., Kamm et al., 1978; Pascoe 1988; Bentler and Cooley, 2001). In general, these studies have found that not only do LDLs vary for people with different hearing losses (especially once the loss exceeds 50–60 dB HL), but they vary significantly for people with the same hearing loss, perhaps as much as 40–50 dB. In an article reviewing several studies on loudness measures, Elberling (1999) estimated that the slope of the measured loudness function (including the LDL) can be predicted from the hearing loss with an accuracy corresponding to a ±5 dB fine-tuning of the gain for 70% of hearing-impaired individuals. He labeled the remaining 30% as either “sound sensitive” (12%) or “sound addicts” (17%). Considering the findings of Bentler and Cooley (2001), however, it is apparent that less than 20% of their subjects fall into the range predicted by the average (±5 dB) across all subjects. If we believe that earphone LDLs are directly related to desired hearing aid output, and that hearing aid output is associated with real-world satisfaction with loudness, this would suggest that 80% of the individuals represented in the Bentler and Cooley (2001) data need an aided maximum output setting other than “average-for-their-hearing-loss.”

**Satisfaction with the Maximum Output of Hearing Aids**

After concluding that LDLs indeed do vary significantly among hearing aid users, it is then reasonable to ask if the maximum output setting of the hearing aid influences acceptance of high-input sounds and overall hearing aid satisfaction. Franks and Beckmann (1985) found that in a group of geriatric patients who rejected their hearing aids, the leading complaint was that the hearing aids “made sounds too loud.” This finding, in fact, was reported by an
overwhelming 88% of the patients. Since the time of the Franks and Beckmann research, compression has become more commonly used, and hearing aids are more adjustable. Excessive output, however, still appears to be a major contributing factor to hearing aid rejection. Kochkin (2000), in a study of 348 hearing aid owners who never use their hearing aids, noted that one of the leading reasons for nonuse was that the hearing aid made sounds too loud. More recently, surveys by Kochkin (2002) have shown that the satisfaction level for people using their hearing aids for the questionnaire item “comfort with loud sounds” was only 42%. Moreover, when hearing aid users were asked what improvements they would like to see in new hearing aid technology, 58% cited “loud sounds less painful” as a highly desirable improvement. In related surveys of audiologists, Jenstad et al (2003) reported that “aids too loud” was the most common complaint of patients fitted with hearing aids. While these surveys all suggest that a significant problem exists, it is important to point out that we do not know if the output of the hearing aids exceeded the LDLs for these dissatisfied hearing aid users. It could be that these complaints are due to other factors unrelated to the LDL.

Indirect evidence that the patient’s LDL is related to hearing aid satisfaction is available from the work of Humes et al (2003). These authors compared a group of individuals who purchased hearing aids and kept them to a group of individuals who purchased hearing aids and returned them. Discriminant analysis revealed that the group that kept the hearing aids had higher LDLs. While Humes et al (2003) did not directly compare hearing aid MPO to the patient’s LDLs, if we consider the mean audiogram of the subjects, the LDL data of Bentler and Cooley (2001), and the OSPL90 of the linear hearing aids these subjects purchased, we would predict that the maximum output would exceed the LDLs of the “average” subject. We would then also predict that the subjects with higher-than-average LDLs would be more accepting of amplification.

Reliability of LDL Measures

In general, research has shown the test-retest reliability for LDLs to be about the same as for pure-tone thresholds and appears to be related to step size (for review see Skinner, 1988; Mueller and Hornsby, 2002). For example, Bentler and Pavlovic (1989) reported a within-session test-retest reliability of 1.2 dB when using a 2 dB step size. Ricketts and Bentler (1996), testing a group of normal-hearing individuals, reported an average within-session test-retest difference of 3 to 4 dB. Hawkins et al (1987), using subjects with hearing impairment, also reported that LDL test-retest variability was small (maximum deviations of 3 to 4 dB over a four-day period).

Currently, many clinicians use the loudness anchors and instructions from the Cox Contour Test (Cox, 1995) to establish unaided LDL. Using this protocol, Palmer and Lindley (1998) found a mean test-retest difference (after a two-week interval) of 2.6 dB across five test frequencies for the #7 rating (“Uncomfortably Loud”); 94% of test-retest differences were less than 10 dB. In summary, these results suggest that LDL reliability meets clinical standards.

CLINICAL USE OF LDL MEASURES

There are two different uses of clinical measure of loudness discomfort. The first involves conducting unaided LDLs (presumably frequency specific) using earphones. This is a prefitting test, often conducted at the time of the diagnostic evaluation, or when the hearing aids are ordered. In this case, either using the clinician’s hand calculations (i.e., adding the reference equivalent thresholds in sound pressure level [RETSPLs, ANSI, 1996] to the hearing level [HL] values to obtain 2-cc coupler values), using stand-alone fitting software, or the manufacturer’s fitting software, these unaided LDL values subsequently are used to select the OSPL90 of the hearing aid (usually the AGCo kneepoint), and/or the knee points and/or ratios of the automatic gain control input (AGCi), if AGCi is used to control the output. For some computerized fitting methods, these values also will change prescribed output (and programmed output) for essentially all inputs. For example, a lower measured LDL will result in a lower calculated maximum comfort level that will result in less programmed gain for average inputs (Mueller, 2003).

The second clinical measure is aided
loudness discomfort, or verification that high input levels are “Loud, But Okay.” Most clinics use a protocol similar to the IHAFF verification approach (Cox, 1995; Mueller, 1999). In this case, the goal of the test is not to determine LDL per se but, rather, deliver high-level inputs to the patient (e.g., speech or environmental noises at 85 dB SPL), which on average should be judged as “Loud, But Okay” (just below the LDL). If these high-level inputs are judged to be either too loud or too soft, the output of the hearing aid is adjusted accordingly.

An alternative verification method for aided maximum loudness would be to use probe-microphone measurements. This primarily is an objective measure. Unaided LDL values (either measured or predicted) are used to generate ear-canal frequency-specific real-ear saturation response (RESR) targets (i.e., by adding real-ear dial difference [REDD] values to HL LDLs). The RESR is then measured, with the fitting goal of placing the measured maximum output just below the target output across the frequency range. A combination of the two approaches also is possible, combining judgments of “too loud” and RESR measures, by simply asking the patient to respond (raise hand/finger) at any time during the RESR measurement that the signal level reaches loudness discomfort.

It has been ten years since Wiley et al (1995) and Bess (1995) stressed the importance of using evidence-based practice in diagnostic audiology and hearing aid fitting. Little has been written in this area, however, regarding the effectiveness of either unaided or aided LDL measures. While the different clinical loudness procedures described above are conducted for the same purpose (to assure that loud sounds in the real world are loud but not too loud), they represent different tests conducted at different times in the hearing aid fitting protocol. It is possible that there is supporting evidence for one, and not the other, and for that reason we address these issues separately in this article.

**METHOD**

**Inclusion and Exclusion Criteria**

The general guidelines of an evidence-based review that are outlined by Cox in this issue of *JAAA* were followed and the six levels of evidence considered. Specifically, our question was “Are the clinical measurements of LDL for adult patients predictive of aided satisfaction of loudness for high inputs in the real world?” For the evaluation of clinical effectiveness, studies were included in the review if they met the following criteria:

- Used either a randomized control, a nonrandomized intervention (aka “quasi-experimental”), or a nonintervention descriptive research design
- Used adult subjects with hearing impairment
- Included *either* unaided or aided LDL measures
- Involved the use of hearing aids in the real world (outside of simulated laboratory conditions)
- Used self-report of loudness acceptance

All studies related to behavioral loudness measures were reviewed. Initially, the senior author reviewed all abstracts, eliminating articles that clearly did not meet review criteria. Both authors then independently reviewed the remaining abstracts (approximately 90), and in some cases the full paper, to determine which articles would be used in the final analysis.

**Search Strategy**

The search strategy was intended initially to identify all articles that had used clinical measures of loudness. Specific key words that were used included loudness, output, uncomfortable, discomfort, tolerance, maximum power, and OSPL90. The databases searched included PubMed, MEDLINE, CINAHL, and EMBASE. In addition, the reference lists of book chapters and recent review articles on loudness discomfort and selecting the maximum power of hearing aids were examined. Key researchers in the area also were contacted to obtain their opinions regarding articles that would meet our research criteria.

Figure 1 reviews the flow of the search process. Initially, 187 articles were identified as being potentially relevant. The majority were eliminated in the first review (n = 173), leaving 14 for a more detailed analysis. It was determined that 11 more articles should be
eliminated. At this final level, the reasons for elimination were these: did not meet level of evidence, did not include self-report outcome measures, or did not directly compare self-report outcome measures to clinical LDL measurements. This resulted in three studies meeting the inclusion criteria and are included in this review. All searches were conducted in January 2005.

**RESULTS**

**Selection Flow**

Figure 1 shows the number of articles that were included or rejected and the reasons for rejection. The articles that met the inclusion criteria were three descriptive studies. All three studies addressed the

**Data Extraction**

Each article was reviewed, with specific attention to the following areas: design, study population, type of LDL measurement (aided versus unaided), and outcome measure used. Given the limited number of studies that met the criteria, and the different procedures and outcomes measures used, it was not possible to pool findings. The outcome of each study, therefore, was rated regarding the clinical effectiveness of unaided and/or aided LDL testing: “++” = strongly support; “+” = support; “=” = equivalent findings; “−” = not support; “−−” = strongly not support.
measure of unaided LDLs, but only two studies combined the use of unaided LDLs with probe-microphone RESR verification measurements. There were no studies using behavioral aided measures of LDL that met our selection criteria.

**Study Characteristics**

The details of each study are summarized in Table 1. Observe that all studies support the contention that if the hearing aid output exceeds some clinical measurement of loudness discomfort, the majority of listeners will report dissatisfaction or excessive loudness for real-world inputs, or conversely (Bratt et al, 2002), if the RESR does not exceed measured LDL, listeners will not report dissatisfaction with real-world inputs. Munro and Patel (1998) used a five-point scale to assess loudness for stimuli with longer (wind noise and/or traffic noise) and shorter (cutlery and glass/door slamming) durations. In their study, the significant outcome indicated that only the longer duration stimuli were responsible for judgments of too much loudness, as SSPL exceeded LDLs for their 20 subjects.

**Study Quality**

A summary of study quality is shown in Table 2. The issue of blinding is not as relevant in this area of research as it might be in other hearing aid studies using a randomized controlled trial design (e.g., noise reduction on versus noise reduction off). For example, in the VA/NIDCD study (Bratt et al, 2002), an attempt was made to adjust all hearing aids so that the maximum output was acceptable, negating the possibility of blinding.

Munro and Patel (1998) recorded the SPL at the eardrum while obtaining measures of LDL. The MPO of the hearing aid was then measured indirectly by adding the subject’s real-ear-to-coupler difference (RECD) to the SSPL90 of the hearing aid. One could conclude that their subjects were “blinded” to the maximum output until the field trial began.

“Follow-up” (drop outs) was not specifically addressed in any of the three studies; no power analysis was reported; and the outcomes used were informally obtained rather than psychometrically developed.
Findings

As shown in Table 1, while there were only three articles that met the criteria, the research reviewed tended to support the clinical procedure of keeping the hearing aid's real ear output below the patient's LDL, which indirectly supports the measure of LDL. The level of evidence was moderate, however, as no study was higher than Level 4 (see Cox in this issue). Moreover, as shown in Table 2, the three studies did not meet many of the desired qualities. This prevents us from making a strong recommendation for routine LDL measurement.

DISCUSSION

Surveys consistently have shown that hearing aid satisfaction is related to the user’s comfort for loud sounds (e.g., Kochkin 2002, 2003). In general, we think of this as being related to real-world sounds being “too loud,” but setting the MPO too low and unnecessarily restricting headroom also has negative consequences. It has been suggested that LDLs and/or hearing aid MPO settings can be predicted accurately from the hearing threshold for a portion of patients, but there is a rather large range of outliers (Eberling, 1999; Bentler and Cooley, 2001; Storey et al, 1998). For this reason, hearing aid fitting protocols recommend the clinical measurement of LDL (e.g., Valente et al, 1998), and the majority of audiologists routinely conduct LDL or loudness verification testing at some point in the hearing aid fitting process. This testing does require 5–15 minutes of clinical time, and therefore, it is reasonable to question the effectiveness of this practice.

As shown in Table 1, positive ratings were assigned to two of the three studies, but an equivocal rating to the VA/NIDCD findings (Bratt et al, 2002). We found this later research difficult to evaluate regarding the effectiveness of LDL testing. On one hand, the results indicate that the unaided LDL is very useful, as when it was used to adjust the maximum output of hearing aids, user complaints of loudness discomfort were essentially nonexistent. On the other hand, for the “approximately 10%” of subjects (i.e., 30 to 40 individuals) where the RESR exceeded the LDL, only one person had a complaint of real-world loudness discomfort. This would suggest that this clinical measure is a poor predictor of real-world acceptance of loud sounds, and it would not be worth the clinical time investment to conduct the test if it only correctly identified one of thirty patients. There are three factors, however, that complicate the interpretation of these data: (1) the RESR may have only exceeded the LDL at one or two frequencies; (2) the subjects reported that the signal was not uncomfortably loud at the time of the RESR testing (even though it exceeded their RESR target); and (3) the experimental hearing aids all had a low OSPL90 (mean = 97–101 dB SPL). Hence, the equivocal rating.

In general, the reviewed research supported the clinical use of unaided LDLs. From a practical standpoint, it is worthwhile to ask how an audiologist selects the hearing aid’s maximum output when he or she does not have a measured LDL. Possible choices would include the following: set the hearing aid to an arbitrary maximum output, set the maximum output to a level that has proven to be successful with past patients, or use a predicted LDL (based on the patient’s thresholds) to calculate a maximum output setting. The alternative choice selected could of course influence the value of the measured LDL. One study that did not meet our criteria

<table>
<thead>
<tr>
<th>Study</th>
<th>Randomization procedures</th>
<th>Blinding</th>
<th>Follow-up ≥80%</th>
<th>Power calculation</th>
<th>Validated outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Munro and Patel (1998)</td>
<td>NA</td>
<td>S</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Note: NA = not appropriate to the design; X = criterion not met; √ = criterion met; C/T = can’t tell; S = single blinding; D = double blinding.
but addresses this issue is that of Storey et al (1998). In the first of two related experiments, these authors measured LDLs for 29 adults with hearing loss and seven adults with normal hearing. Next, the acceptability of different OSPL90 settings was investigated in a laboratory setting. From those comparisons, it was determined that the OSPL90s predicted by a threshold-based formula (Dillon and Storey, 1998) were within the acceptable range for 86% of the subjects. Further investigation, in the form of a field trial with 32 subjects, indicated that for 63% of the subjects, the predicted OSPL90 was within 2 dB of the acceptable range. The authors note that “incorporating individual measures of loudness discomfort into the formula did not improve accuracy significantly.” This research did not meet our criteria because there was not a direct comparison between field study results and the patient’s measured LDL. Inferences, however, would suggest that the unaided LDL is not useful if the prescriptive LDL is reasonably valid, but some type of clinical aided loudness verification testing is necessary to account for the errors of the predictive output setting (e.g., the 37% who fell outside of the range).

Two of the three studies we reviewed utilized real-ear SPL measures of hearing aid output, which were then compared to the patient’s LDL, to determine the appropriateness of the output setting. This procedure requires that a common reference is used for comparison. In clinical practice, the HL LDL typically is converted to ear-canal SPL by adding the average REDD (average RECD + RETSPL). The output of the hearing aid is then measured in ear-canal SPL, allowing for the common reference. The problem with using average RECDs for REDD calculation is that even with adults, the RECD can be quite variable, with standard deviations of 4–5 dB (Saunders and Morgan, 2003). When the output of the hearing aid is measured, the average RECD is not considered, as the patient’s RECD indirectly is part of the measurement. The outcome for patients that are not “average” will be that LDL/hearing aid output values that appear to match do not, and vice versa. This variable was well controlled in both studies cited. In the Bratt et al (2002) study, the RECD was measured for each individual (and then used with the RETSPL) to convert HL LDLs, and the RESR was measured directly. The Munro and Patel (1998) research used probe microphones to measure the frequency-specific LDL in ear canal SPL (avoiding the use of the REDD correction) and used the patient’s RECD to calculate the RESR (so that the patients did not know before the field trial that their hearing aid made loud sounds uncomfortable).

Because the research reviewed utilized field trials of different lengths, it is also important to address the issue of acclimatization of loudness for hearing aid users. In other words, do hearing aids users “get used to” high inputs that initially are uncomfortably loud or annoyingly soft? Acclimatization also impacts on the effectiveness of the clinical LDL measure if that measure is being used to adjust hearing aid output. In general, research has shown that if changes in the LDL over time occur, they are small and could be related to a training effect for the procedure (Byrne and Dirks, 1996). To some extent, this also could be related to whether the MPO initially was set correctly (Bentler et al, 1993; Mueller and Powers, 2001). It is unlikely that acclimatization influenced the outcomes of the research reported here. In fact, Bratt et al (2002) followed changes in LDL measures over a nine-month period and noted an average increase of the LDL of only 1–3 dB across the five frequencies observed (500, 1000, 2000, 3000, and 4000 Hz). While this change was significant in this study, it is not large enough to impact fitting decisions and could simply be due to a training effect from repeated LDL testing.

As discussed, two studies that we reviewed utilized real-ear SPL to adjust the output of the hearing aids. There are compelling reasons, however, to supplement these measures with behavioral aided loudness verification testing using a broad-band signal, such as speech (Mueller and Bentler 2002; Mueller and Hornsby, 2002). First, loudness summation effects could be present for speech, which are not observed in the unaided LDL measurements used for RESR targets; monaural loudness summation does vary among individuals with cochlear hearing loss. Another issue is binaural summation, an effect that cannot be measured in the ear canal. The effects of binaural summation on the aided LDL are difficult to predict (e.g., Hawkins et al, 1987;
A third issue is channel/power summation for hearing aids with multichannel compression (Dillon, 2001). This is another factor that could influence the patient’s acceptance of loud sounds and that cannot be predicted from the frequency-specific LDL measure.

As just discussed, although aided loudness verification for high input signals appears intuitively useful and is recommended in the Valente et al (1998) protocol, none of the studies that met our criteria employed aided LDL testing using broad-band material. Only two of the 14 publications that were in our final consideration category used aided LDL measures, and neither of these survived to the final review. Bratt et al (2002) did solicit subjective comments when conducting the swept-tone RESR. The absence of real-world evidence in this area is puzzling, as the clinical measurement of aided loudness discomfort has been part of hearing aid fitting protocols for at least 60 years; for example, it was included in Step #2 and Step #3 of the 1946 Carhart fitting method. In part, this could be because at first glance, it does not appear to be a very interesting research question, as the outcome seems almost too obvious. That is, it is intuitive in clinical testing that if a patient says the high level input to the hearing aid makes things too loud, reducing the MPO of the hearing aid will probably make things better. The research of Filion and Margolis (1992), however, indicates that the relationship between clinical adjustment and patient complaint may not be this straightforward. Their research showed that signals judged as uncomfortable in the clinic may be not judged as uncomfortable in the real world. While the strength of their research suffers because of the use of a small number of normal-hearing subjects, because hearing aids were not involved, and because of the potential influence of the “nightclub setting,” the overall design addresses an important area. More research of this type is needed.

Finally, it is important to remind the reader that this evidence review and the resultant recommendations are related to frequency-specific unaided LDL measurements. This is the LDL procedure that is considered preferred practice and recommended in contemporary fitting methods and protocols (e.g., Cox 1995; Seewald et al, 1997; Valente et al, 1998). We recognize, however, that measuring unaided speech LDLs remains popular (Mueller, 2003). This review did not produce any studies that addressed the effectiveness of that procedure.

In summary, the evidence shown here tends to support the use of clinically measured frequency-specific LDLs for selecting the real ear maximum output of hearing aids. However, the dearth of studies, the low statistical power of the studies, and the level of the evidence prevents us from making a strong recommendation supporting this clinical procedure. Research on this topic employing randomized controlled trials would be a useful addition to this body of literature.

Acknowledgment. We would like to thank Shuman He for her help in the preparation of the manuscript and Mike Valente for his helpful editing and comments on an earlier draft.

NOTES

1. The term “loudness discomfort level” (LDL) is used in this paper to describe the intensity that an individual judges a signal to be uncomfortable. Two other common terms used in the literature are “uncomfortable level” (UL or UCL) and “threshold of discomfort” (TD). In some studies, these terms have been used to mean different things (for review, see Mueller and Bentler, 1994). For this paper, however, the reader should consider the LDL, UL, UCL, and TD the same clinical measure.

2. The maximum output of a hearing aid usually is referred to as the OSPL90 (ANSI S3.22-1996). The standard recommends that this measurement is conducted with gain turned to maximum and compression parameters turned off. In some studies reviewed here, however, the hearing aids employed AGCi, and the maximum output of the hearing aid was controlled by the AGCi. Hence, during use, it is possible that the hearing aids did not reach their OSPL90. For this reason, we have used the term “maximum power output” (MPO), as it is less specific and does not have prescribed measurement parameters.

3. In fact, Bratt et al (2002) was not a stand-alone descriptive study but a portion of a large randomized control trial. The data provided in this report were intended to provide evidence of stability and accuracy of circuit and loudness perception measures.
REFERENCES


