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Hearing Aid Maximum Output and Loudness Discomfort: Are Unaided Loudness Measures Needed?

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Abstract

The purpose of this study was to evaluate a clinical protocol for setting hearing aid maximum output (MPO) in adult users. The protocol consisted of matching prescriptive targets for MPO followed by aided loudness validation and adjustment. Twenty-eight adults fit with multichannel hearing aids during the previous two years were recalled for unaided loudness measures. During the recall visit, unaided frequency-specific loudness discomfort levels were measured for frequencies between 250 and 3000 Hz. These values were converted to real-ear levels by adding individually measured real-ear dial differences. Real-ear saturation responses (RESR) were measured using a 90 dB pure-tone sweep and compared to the real-ear loudness discomfort levels. All participants completed the APHAB Aversiveness scale and Munro-Patel loudness questionnaire. A subset of participants (n = 20) completed the Profile of Aided Loudness.

The average RESR-UCL difference was -5.7 dB, and the maximum difference was 15 dB. For all but one participant, the average RESR values (.5–3 kHz) were either less than or no more than 5 dB above the LDLs, and the aided APHAB Aversiveness scores were below the 80th percentile. There were no significant correlations between the scores on the loudness questionnaires and the differences between RESR and LDL values. Results suggest that unaided LDL measures may be redundant if aided loudness validation measures are completed.

Key Words: Hearing aids, loudness discomfort, loudness perception, maximum output

Abbreviations: APHAB = Abbreviated Profile of Hearing Aid Benefit; LDL = loudness discomfort level; PAL = Profile of Aided Loudness; REDD = real-ear dial difference; RESR = real-ear saturation response

Sumario

El propósito de este estudio fue evaluar un protocolo clínico para la graduación de la salida máxima (MPO) de un auxiliar auditivo para usuarios adultos. El protocolo consistió en unir metas de prescripción para MPO seguido de una validación amplificada y ajustes en la apreciación subjetiva de la intensidad (sonoridad). Veintiocho adultos que habían sido adaptados con auxiliares auditivos multi-canal durante los dos años anteriores, fueron sometidos a

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mediciones de sonoridad sin amplificación. Durante la evaluación, se midieron niveles de molestia de frecuencia específica para la sonoridad en las frecuencias entre 250 y 3000 Hz. Estos valores se convirtieron en niveles de oído real adicionando mediciones individuales de las diferencias de dial para oído real. Se midieron respuestas de saturación de oído real (RESR) usando un barrido de tonos puros a 90 dB y comparándolo con los niveles de oído real de molestia en la sonoridad. Todos los participantes completaron la escala APHAB de aversión al sonido y el cuestionario Munro-Patel de sonoridad. Un subgrupo de participantes completó el Perfil de Sonoridad con Amplificación. La diferencia RESR-UCL fue de -5.7 dB, y la diferencia máxima fue de 15 dB. Para todos excepto uno de los participantes, los valores promedio de RESR (0.5--3 kHz) fueron menores o no más de 5 dB por encima del LDL, y los puntajes APHAB de aversión al sonido estuvieron por debajo del percentil 80. No existió una correlación significativa entre los puntajes de los cuestionarios de sonoridad y las diferencias entre los valores del RESR y el LDL. Los resultados sugieren que las medidas no amplificadas del LDL pueden ser redundantes si se completan las medidas de validación de la sonoridad.

Palabras Clave: Auxiliares auditivos, molestia con la apreciación subjetiva de la intensidad (sonoridad), percepción de la apreciación subjetiva de la intensidad, salida máxima

Abreviaturas: APHAB = Perfil Abreviado del Beneficio del Auxiliar Auditivo; LDL = nivel de molestia en la apreciación subjetiva de la intensidad (sonoridad); PAL = Perfil de apreciación subjetiva de la intensidad con amplificación; REDD = diferencias en el dial para oído real; RESR = respuesta de saturación en oído real

One crucial component of the hearing aid fitting process is the adjustment of the maximum output. The main consequence of setting the maximum output too high is the problem of aided loudness discomfort for high-level sounds. Indeed, loudness discomfort has been cited as a reason for dissatisfaction with hearing aids. Based on a survey of over 2600 hearing aid users, Kochkin (2002) noted that 27% of the respondents reported dissatisfaction with loud sounds. There is also indirect evidence that aided loudness discomfort may be a factor in successful hearing aid use. For example, in a survey of 348 respondents who do not use their hearing aids, Kochkin (2000) reported that "hearing aids too loud" ranked 16th in a list of 32 reasons why respondents did not use the aids, accounting for 2.3% of the reasons given. In addition, Humes et al (2003) noted that unsuccessful hearing aid users often have low loudness discomfort levels (LDL), though a direct connection between the hearing aid settings and LDLs was not established.

While these reports suggest that issues related to loudness discomfort may influence the satisfaction and ultimate success of a hearing aid fitting, a description of procedures used to determine maximum output was not included in the studies cited above. In addition, aided loudness problems may be related to other factors such as excessive overall gain or instrument distortion. It is not clear, therefore, whether the aided loudness problems cited in the studies described above were attributable to an omission of one or more fitting/verification loudness measurement procedures or whether the problems would have occurred despite the use of appropriate clinical measures.

There is general agreement that setting the maximum output below loudness discomfort is an important objective of any hearing aid fitting. There is a lack of consensus, however, regarding the best way to approach this objective. One view is that maximum output should be based on individually measured loudness data. A contrasting view is that maximum output can be determined using a prescriptive approach based on average loudness data. Proponents of the first view suggest that unaided frequency-specific loudness growth measures are needed to ensure that hearing aid maximum output is set below individually determined loudness discomfort levels (Valente et al, 1998; Mueller, 2003). The underlying assumption is that setting the hearing aid maximum output below the unaided loudness discomfort levels for frequency-specific stimuli will ensure that the hearing aid does not amplify high real-world high-intensity sounds above the user's discomfort levels. Proponents of this view cite evidence documenting the wide range of variability in discomfort levels as a function of hearing loss. They suggest that this variability precludes the accurate prediction for individual patients (Mueller, 2003; Mueller and Bentler, 2005).

There is some evidence to suggest that maximum output levels set substantially above unaided LDLs result in more reported loudness discomfort problems with amplification. Dillon et al (1984), for example, examined the difference between maximum output and loudness discomfort levels for two groups of hearing aid users: one group reporting aided loudness discomfort problems and the other group denying loudness problems. All listeners without problems had maximum output values either less than the LDLs or less than 5 dB above the LDLs. In contrast, the majority of users who reported loudness problems had maximum output values that exceeded LDLs by more than 10 dB. In a similar study, Munro and Patel (1998) examined the association between the amount by which the real-ear saturation response (RESR) exceeded the loudness discomfort levels and responses on a questionnaire designed to reveal aided loudness tolerance problems. They found a significant correlation between the frequency of reported loudness problems reported for long duration sounds and the difference between the ear canal saturation response and LDLs. Those with greater differences between ear canal saturation response values and LDLs were more likely to report frequent aided loudness discomfort problems. Although the studies by Dillon et al (1984) and Munro and Patel (1998) suggest a link between LDLs and real-world loudness problems, the procedures used to set the maximum output in these studies were not described. Therefore, a direct connection between the loudness problems reported in these studies and the need for unaided loudness measures cannot be made.

An alternate approach relies on prescription of maximum output based on LDL predictions from hearing thresholds (e.g., Dillon and Storey, 1998; Storey et al, 1998). A validation study of the NAL OSPL-90 prescriptive approach showed that for single-channel hearing aids, the maximum output determined using the prescription fell within an acceptable range for roughly 86% of the hearing aid users (Storey et al, 1998). A similar study conducted by Preminger et al (2001) using a two-channel hearing aid revealed that the prescribed maximum output was within the acceptable range 85% of the time for the low-frequency channel and 65% of the time for the high-frequency channel. These results suggest that a prescriptive approach may be an adequate starting point for determining the initial maximum output settings. The data of Storey et al (1998) do not support the conclusion that individually determined unaided loudness measures would provide a better starting point.

Despite the controversy regarding whether to base maximum output on individually measured unaided LDLs or use a prescriptive approach, proponents of both approaches generally agree that ensuring loudness comfort at the time of the hearing aid fitting is an important component of the fitting process (Valente et al, 1998; Preminger et al, 2001; Mueller and Hornsby, 2002; Scheller, 2004). In addition, it is generally agreed that one should also avoid setting the maximum output too low in order to maintain adequate headroom.

The general goal of the present study was to determine if unaided loudness measures are needed if aided loudness validation and real-ear verification of maximum output are completed at the time of the fitting. The study was designed to address the following questions: (1) Does the combined prescriptive/aided loudness protocol result in real-ear saturation response values lower than, or close to, individually measured unaided loudness discomfort levels? and (2) What is the relationship between reported loudness discomfort problems with amplification and the difference between real-ear saturation response values and unaided LDLs? Based on previous work (Dillon et al, 1984; Munro and Patel, 1998), it was predicted that if the protocol resulted in RESR values that exceeded LDLs by more than 10 dB, there would be a corresponding increase in reported loudness discomfort problems with hearing aid use.

METHODS

Participants

The data reported here were obtained from a retrospective review of clinical records of 28 adults who purchased hearing aids within the previous two years. Participants ranged in age from 53 to 95 years, with an average age of 74 years. Pure-tone average thresholds (500, 1000, 2000 Hz) ranged from 23 to 63 dB HL with a mean of 44 dB HL. Twenty-two of the 28 participants were binaural hearing aid users. Nineteen were experienced hearing aid users, and the remaining nine were new users. All users wore multichannel hearing aids with between 2 and 15 channels.

Hearing Aid Fitting Process

Details of the hearing aid fitting process used in this investigation are described below. All participants were seen for hearing aid fitting and follow-up visits before they were recalled for the formal outcome evaluation.

Hearing Aid Fitting Procedure

Participants were fit using the clinic's standard protocol. Initial hearing aid settings were based on NAL-NL1 targets for gain and maximum output (Byrne et al, 2001). Probe microphone measures were completed using a 50 and 65 dB SPL digital ANSI speech-weighted signal to verify the frequency response (Fonix 6500CX). Further adjustments to gain were made as needed to ensure participant audibility and comfort for low-, average, and high-level speech presented at 50, 65, and 80 dB SPL, respectively.

Real-ear saturation responses were measured using a 90 dB SPL pure-tone sweep. If participants experienced loudness discomfort during any part of the pure-tone sweep, the maximum output of the hearing aid was reduced. Feedback reduction circuits were disabled during this procedure whenever possible. This procedure was repeated, if necessary, until the pure-tone sweep no longer resulted in loudness discomfort. In addition, a high-intensity broad-band signal (e.g., high-intensity speech, clapping near the ear) was presented informally to verify that participants did not experience loudness discomfort resulting from loudness summation.

Hearing Aid Follow-Up

Following the fitting session, participants were seen for a minimum of two follow-up visits prior to the outcome evaluation. During the follow-up visits, adjustments to gain, maximum output, and other programmable features were made as needed to address participants' feedback regarding their experiences with amplification. No gain or maximum output adjustments were made during the course of follow-up for 13 participants. For four participants, high-level gain (and maximum output) was reduced slightly (3–4 dB) during one follow-up visit in the low-frequency region (250–500 Hz). Overall gain (all input levels) was decreased for one participant and increased for five participants. Overall gain was both increased and decreased during the course of the follow-up visits for seven participants. Other changes were sometimes made during the follow-up visits (e.g., gain for low-level sounds, frequency response, telephone, and other programmable features).

Outcome Evaluation

The measures that form the focus of the current study (described below) were completed as part of an outcome evaluation to evaluate the clinical protocol for setting hearing aid maximum output. Outcome evaluations were scheduled a minimum of two months after the hearing aid fitting. Additional performance (speech perception) and subjective outcome measures completed as part of the clinical protocol are not included in this report as they were not the focus of the current investigation.

Loudness Growth Measures

Categorical loudness ratings were completed using an ascending procedure similar to that described by Hawkins et al (1987) and Cox and Gray (2001). Speech and pure-tone stimuli were delivered through TDH-59 earphones. Participants were asked to rate the loudness of sounds on an eight-point scale, with 1 corresponding to "cannot hear," "7" corresponding to "loud, but ok," and "8" corresponding to "uncomfortably loud." A rating of "8" was taken as the loudness discomfort level (LDL). Two ascending runs were completed using a 5 dB step-size for 250, 500, 1000, 2000, 3000, and 4000 Hz pure tones. A third run was completed if the LDL of the two runs differed by more than 5 dB. The final LDL estimate was based on the mean of the individual runs. To convert the dial levels to ear canal sound-pressure levels, the real-ear dial differences (REDD) for these stimuli were determined using the AudioScan RM500. The REDD is the difference between the real-ear intensity level (dB SPL) and the audiometer intensity dial level. Ear canal LDL sound-pressure levels were determined by adding the REDD to the LDL dial level recorded for each frequency.

Self-Report Loudness Questionnaires

At the time of the outcome evaluation, all participants completed the Aversiveness subscale of the Abbreviated Profile of Hearing Aid Benefit (APHAB; Cox and Alexander, 1995) and the Munro-Patel loudness scale (Munro and Patel, 1998). The APHAB Aversiveness scale consists of six questions related to loudness of sounds with and without hearing aids. Respondents are asked to rate the frequency of the problems on a seven-point scale ranging from "never" to "always." The Munro-Patel questionnaire consists of four questions about the loudness of environmental sounds categorized as having either long (wind noise, traffic) or short durations (cutlery/glass, door slamming). Respondents are asked to judge the loudness of these sounds on a five-point scale ranging from "always too soft" (1) to "always too loud" (5). In addition, a subset of participants completed the Profile of Aided Loudness (PAL; Mueller and Palmer, 1998; Palmer et al, 1999). The PAL was not completed by eight of the participants because it was added to the outcome protocol more recently. The PAL consists of 12 questions related to the loudness of sounds that represent a range of levels (soft, average, loud). Respondents are asked to recall the loudness of sounds experienced while wearing their hearing aids and rate the loudness on a seven-point scale ranging from "do not hear" (0) to "uncomfortably loud" (7).

Verification Measures

During the outcome evaluation, the verification measures were repeated using the Fonix 6500CX. Verification of low- and average-level sounds was completed using a digital speech-weighted signal (ANSI, 1992), and real-ear saturation responses were measured using a 90 dB pure-tone sweep. Participants were asked to report if any sounds were uncomfortably loud.

RESULTS

RESR-LDL Differences

The number and percentage of subjects with RESR-LDL differences less than 5 dB (including negative values), 5–10 dB, and greater than 10 dB are shown in Table 1. The greater the RESR-LDL difference, the more the real-ear sound pressure levels exceeded the ear canal LDLs. For participants with binaural hearing aids, the worst case was considered (i.e., the ear in which the RESR-LDL differences were the greatest). The average RESR-LDL differences between .5 and 3 kHz are shown on the left, and the largest RESR-LDL differences at any frequency are shown on the right. The group mean RESR-LDL differences between .5 and 3 kHz was -5.7 dB (RESR lower than LDLs). Results from Munro and Patel (1998) are shown for comparison. It can be seen that there was only one instance (of 28 cases) in which the average RESR exceeded the average ear canal LDL between .5 and 3 kHz by more than 5 dB. In contrast, Munro and

Table 1. Numbers and Percentages of Total Cases of RESR-LDL Differences

	Average (.5-3 kHz)		At least 1 frequency	
	n Cases	%	n Cases	%
Current study				
RESR-LDL <5 dB	27	96	23	82
RESR-LDL 5–10 dB	0	0	3	11
RESR-LDL >10 dB	1	3	2	7
	n Cases	%	N Cases	%
Munro and Patel, 1998				
RESR-LDL <5 dB	13	65	NA	
RESR-LDL 5–10 dB	4	20	NA	
RESR-LDL >10 dB	3	15	NA	

Note: Average RESR-LDL differences (0.5–3 kHz) are shown on the left, and the maximum RESR-LDL differences at any frequency (worst case) are shown on the right. Data from Munro and Patel (1998) are shown for comparison.

Patel (1998) found that average RESRs exceeded average LDLs by more than 5 dB in 35% (n = 7) of the cases.

Using a more conservative analysis that considers the greatest RESR-LDL difference at any frequency rather than average RESR-LDL difference, there were 5 of 28 cases in the present study in which RESR exceeded LDLs by 5 dB or more. It is important to note, however, that no participant reported discomfort to the high-intensity pure-tone sweep presented during the reevaluation of RESR on the day the ear canal LDLs were measured.

Aided Loudness Questionnaires

In the sections below, results of three aided loudness questionnaires are considered in relation to the excess output. Differences between RESR and ear canal LDL measures are presented as both the average RESR-LDL difference between .5 and 3 kHz (as in Munro and Patel, 1998) and as the largest difference at any frequency/ear.

For the purposes of this report, hearing aids were categorized as having either "basic" or "advanced" processing. Aids with "basic" processing had fewer than five compression channels, omnidirectional microphones, and no digital noise reduction circuit. Hearing aids with advanced processing had five or more compression channels and digital noise reduction. In addition, all but two participants (CIC users) with aids categorized as have advanced processing had either fixed or adaptive directional microphones. In the figures presented below, the open triangles denote participants who wore hearing aids with basic processing (n = 12), and the circles denote participants with more advanced processing (n = 16).

Munro-Patel Questionnaire

Combined scores for the long duration items of the Munro-Patel questionnaire plotted as a function of the RESR-LDL differences are shown in Figure 1. The x-axis shows the extent to which the RESR exceeds the LDL. A positive value indicates that the RESR exceeds the LDL. The average RESR-LDL differences (.5–3 kHz) are shown in the top panel (A), and the maximum (worst case) RESR-LDL differences for any frequency are shown in the bottom panel (B). The mean scores for participants with basic and advanced processing were similar (6.75 and 6.87 for basic and advanced processing, respectively). There is little association between the questionnaire scores and the average RESR-LDL differences, as indicated by the low Pearson-Product moment correlation ($r [27] = 0.07$, $p > .05$). These results are quite different from those reported by Munro and Patel (1998), who showed a moderate association between these average RESR-LDL differences and the frequency of reported loudness problems ($r = .75$) that accounted for 56% of the variance.

APHAB Aversiveness Scale

The aided APHAB Aversiveness scores are plotted as a function of the RESR-LDL differences in Figure 2. The x-axis shows the extent to which the RESR exceeds the LDL.

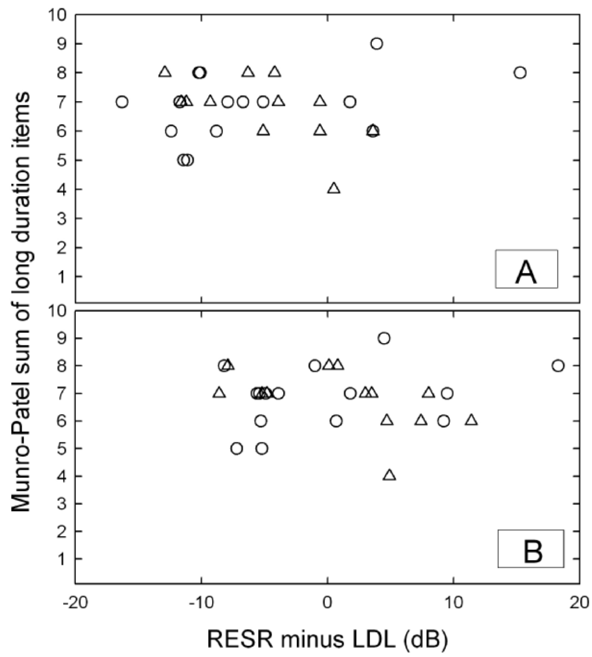

Figure 1. Individual scores for the sum of the long duration items from the Munro and Patel (1998) loudness questionnaire plotted as a function of the difference between RESR values and ear canal LDLs. The average RESR-LDL differences between .5 and 3 kHz are shown in the top panel *(A)*, and the maximum RESR-LDL differences for any frequency are shown in the bottom panel *(B)*. Triangles represent individuals fit with "basic" signal processing, and circles represent individuals fit with "advanced processing."

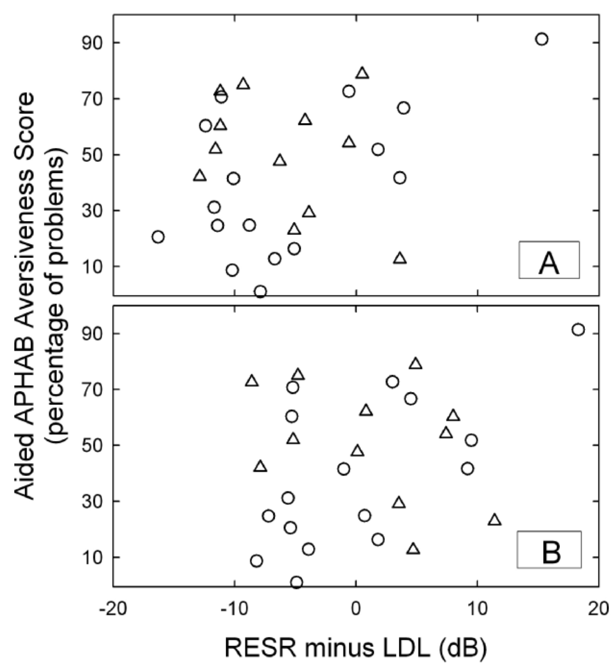

Figure 2. Individual scores from the APHAB Aversiveness scale plotted as a function of the difference between RESR values and ear canal LDLs. The average RESR-LDL differences between .5 and 3 kHz are shown in the top panel *(A)*, and the maximum RESR-LDL differences for any frequency are shown in the bottom panel *(B)*. Triangles represent individuals fit with "basic" signal processing, and circles represent individuals fit with "advanced processing."

A positive value indicates that the RESR exceeds the LDL. The average RESR-LDL differences (.5–3 kHz) are shown in the top panel, and the maximum (worst case) RESR-LDL differences for any frequency are shown in the bottom panel. The mean aversiveness score (44) was somewhat lower than the mean score (55) reported by Cox and Alexander (1995) for linear aids. The Pearson-Product moment correlation between these APHAB scores and RESR-LDL differences was not significant for either the average RESR-LDL differences (r [27] = .32, p > .05) or the maximum RESR-LDL differences at any frequency (r[27] = .28, p > .05). The mean aversiveness scores for participants with basic and advance processing were 50.8 and 39.8, respectively. These scores were not significantly different from one another [t(26) = 1.18, p = .25]. There was considerable overlap between data points for the participants with basic and advanced processing.

For a given RESR-LDL difference, the intersubject variability of APHAB Aversiveness scores was large. For example, the APHAB Aversiveness scores of individuals who had RESR values 4–10 dB less than LDLs ranged from 12 to 71. Interestingly, the range of APHAB scores was fairly similar (12–78) for individuals whose RESR values exceeded LDLs by 4–10 dB. Thus, there was not a general tendency for people whose RESR exceeded their LDLs to report greater aversiveness to loud sounds as measured by the APHAB. Although the variability in APHAB scores is large, the standard deviation of this relatively small sample (SD = 24.6) was similar to the standard deviation reported by Cox and Alexander (1995) and Purdy et al (1998). For all but one participant, the APHAB scores fell below the 80th percentile based on the normative data for hearing aid users (Cox and Alexander, 1995). There was, however, one participant whose APHAB score exceeded the 80th percentile and whose RESR-LDL differences exceeded 10 dB. More information about this outlier

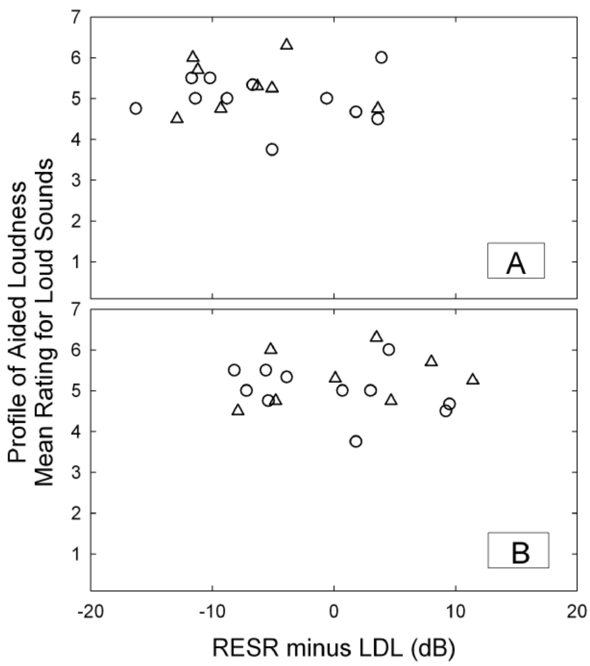

Figure 3. Individual loudness rating scores from the Profile of Aided Loudness (PAL) plotted as a function of the difference between RESR values and ear canal LDLs. The average RESR-LDL differences between .5 and 3 kHz are shown in the top panel *(A)*, and the maximum RESR-LDL differences for any frequency are shown in the bottom panel *(B)*. Triangles represent individuals fit with "basic" signal processing, and circles represent individuals fit with "advanced processing."

will be provided in a later section.

Profile of Aided Loudness (PAL)

A subset of the sample (n = 20) completed the Profile of Aided Loudness (Mueller and Palmer, 1998; Palmer et al, 1999). Eight of the participants did not complete the questionnaire because the PAL was added to the outcome protocol later. In Figure 3, the PAL scores are plotted as a function of the average RESR-LDL difference (.5–3 kHz) (top panel [A]) and as a function of the largest RESR-LDL value at any frequency (bottom panel [B]). The x-axis shows the extent to which the RESR exceeds the LDL. A positive value indicates that the RESR exceeds the LDL. As shown in the figure, there is no evidence of a systematic relationship between the aided loudness ratings on the PAL and the mean difference between the RESR and ear canal LDLs. There is considerable overlap between data points for participants with basic and advanced processing.

The mean PAL ratings for loud sounds ranged from 4.0 to 6.3 with a mean of 5.2. This result compares favorably to the mean of 5.9 for normal-hearing subjects (Palmer and Mueller, 2000). No participants in this subgroup had mean aided loudness ratings close to "uncomfortably loud" (7) for items on the PAL questionnaire. It is important to note that the outlier is not included in the subgroup of participants who completed the PAL because he was seen at the clinic before the questionnaire was added to the protocol.

Outlier Profile

For a single outlier, the RESR-LDL differences exceeded 10 dB, and the corresponding aided APHAB score (91) exceeded the 80th percentile (Cox and Alexander, 1995). In addition, the Munro-Patel score of 8 for the long duration items indicated that the long duration sounds (wind, traffic) were reported as being "often too loud." Based on these results, one might expect that this 88-year-old male would be an unsuccessful (or at least dissatisfied) hearing aid user. Based on the results of the Glasgow Hearing Aid Difference Profile (GHADP) and International Outcome Inventory for Hearing Aids (IOI-HA), however, this did not appear to be the case. The GHADP indicated full-time hearing aid use in all listening situations and a mean satisfaction rating of 4.25/5 (4 = "very satisfied"). The IOI-HA score (summed across items) was 32/35, and scores for all items on the IOI-HA were within the middle 50% of scores in the normative data reported by Cox et al (2003). At the time of the outcome evaluation, adjustment of amplification was recommended to reduce the maximum output. Despite this recommendation, the participant did not allow the audiologist to adjust his hearing aid settings, stating that he was happy with the current settings of his hearing aids.

DISCUSSION

The fitting protocol, consisting of a combination of prescriptive measures and aided loudness verification, resulted in average RECD values no more than 5 dB above the LDLs for all but one participant. When considering the largest RESR-LDL difference at any single frequency, 93% of the participants had RESR-LDL differences ±10 dB. APHAB scores were within the 80th percentile for all but one participant. These findings contrast with those of Munro and Patel (1998), who reported a higher percentage of participants whose hearing aid settings exceeded the LDLs by 5 dB or more. One possible factor that may account for the differences between the two studies is that linear hearing aids were used by many of the participants in the Munro and Patel study whereas all participants in the current study had compression hearing aids (K.J. Munro, pers. comm.). A second difference between the two studies concerns the instructions used to obtain loudness discomfort levels. In the Munro and Patel study, participants were asked to indicate when "the signal first reached a level of definite discomfort," whereas a descriptive anchor of "uncomfortably loud" was used in the current study. The instructions used in the Munro and Patel study could be regarded as being more conservative than the instructions used in the current study. The more conservative instructions used by Munro and Patel might have resulted in lower LDLs, which would tend to lead to greater differences between LDLs and RESR values. Finally, information regarding fitting/verification of maximum output for participants in the Munro and Patel (1998) study is not available. Therefore, is not clear whether the fitting/loudness verification procedures for this study and the Munro and Patel (1998) study were equivalent.

There were no systematic relations between the RESR-LDL differences and the loudness questionnaire data for any of the questionnaires used. The findings of the present study contrast with those of Munro and Patel (1998), who found a significant association between RESR-LDL differences and the frequency of aided loudness problems. It is important to note that, although the range of average RESR-LDL differences in the present study was similar to that of Munro and Patel, the distributions of average RESR-LDL differences were not the same. Specifically, most data points were concentrated below 5 dB in the present study whereas data points in the Munro and Patel study were more evenly distributed across the range, a factor that may affect the correlation coefficients somewhat.

Another factor that may account for the weak association between RESR-LDL differences and loudness questionnaire data relates to differences among the hearing aids used in the current study. There were considerable differences in the processing characteristics of the aids worn by participants in the present study. As noted earlier, hearing aid differences included differences in the number of channels, compression characteristics, noise reduction processing, and directional characteristics. It is possible that some of these characteristics impacted the responses to the loudness questionnaires. Such an influence might weaken the relations between the RESR-LDL differences and questionnaire data. Based on mixed reports in the literature, however, the influence of various processing characteristics on the frequency of aided loudness problems is unclear. One study comparing directional and omnidirectional microphone systems showed mixed results, with a significantly lower frequency of loudness problems reported with directional microphones at one test site but no significant differences at the other test site (Valente et al, 1995). Several other studies, however, have not shown significant differences between loudness aversiveness ratings for directional and omnidirectional microphone systems (Preves et al, 1999; Ricketts et al, 2003). Similarly, there is conflicting evidence regarding the effects of digital noise reduction systems on the frequency of reported loudness discomfort problems as measured by the APHAB (Arlinger et al, 1998; Wood and Lutman, 2004). In the current study, there was no clear differentiation between questionnaire scores for users of basic (i.e., no noise reduction, no directional microphones) versus more advanced signal processing. Nevertheless, because the influence of various processing features could not be examined independently in the current study, the influence of signal processing on the strength of the relations between RESR-LDL differences and questionnaire data remains unclear.

Although there were some participants whose RESR values exceeded their LDLs, the differences did not appear to be large enough to result in consistent aided loudness discomfort problems as measured by subjective questionnaires. In fact, the proportion of problems experienced by most participants whose RESR values exceeded their LDLs were similar to the proportion of problems experienced by participants whose RESR values were below their LDLs. Excluding the outlier, the range of differences between RESR values and LDLs was ±10 dB, which is similar to the test-retest range of the "uncomfortably loud" category rating reported by Cox et al (1997). Thus, the variability of RESR-LDL differences could simply reflect the normal variability of LDL data. If this were the case, then an association between RESR-LDL differences (over the 20 dB range reported here) and loudness questionnaire data would not be expected.

There are several limitations concerning the retrospective nature of this study. Because the study considered participants up to two years after the fitting, possible changes in loudness tolerance following the initial fitting were not considered. There is evidence to suggest that loudness discomfort levels increase over time for individuals fit with unilateral hearing aids (Munro and Trotter, 2006), although the generalizability to bilateral fittings is unclear. In addition, it is not clear if the number of hearing aid changes made during the follow-up visits would be similar for fittings based on the protocol used in this study versus a protocol based on individually measured unaided loudness discomfort levels. A prospective study is needed to resolve these questions and to provide more information regarding the influence of signal processing.

The question of how large the RESR-LDL differences need to be to result in excessive aided loudness has not yet been adequately addressed. It is interesting to note, however, that the majority of hearing aid loudness problems reported by Dillon et al (1984) had RESR-LDL differences of more than 10 dB, similar to the single outlier with reported loudness problems on the APHAB and Munro-Patel questionnaire in the present study.

Results of the current study suggest that maximum output settings based on unaided loudness discomfort measures are essentially equivalent to a prescriptive approach combined with aided loudness validation for high-intensity sounds. The prescriptive approach is more efficient, however. Clinicians who wish to use unaided loudness discomfort measures in the fitting process must also consider the possibility that peaks in the RESR may not correspond to the limited frequencies at which unaided loudness discomfort is typically measured. Therefore, regardless of the approach used, loudness validation using high-intensity signals should be included during the fitting process.

At least one set of fitting guidelines for adults recommends that hearing aid maximum output be based on frequency-specific unaided loudness measures (Valente et al, 1998). The authors of a recent systematic review of this topic, however, were unable to make a strong recommendation supporting the use of unaided loudness discomfort measures, because of the low level of evidence and small number of studies available (Mueller and Bentler, 2005). Results of the present study do not support the need for unaided loudness measures for the protocol reported here. Rather, results suggest that initial setting of maximum output for a multichannel hearing aid may be based on the NAL-NL1 prescriptive approach provided that aided output verification and loudness validation is completed at the time of fitting. Generalization of the present findings to other prescriptions of maximum output may not be appropriate as some prescriptions allow for higher maximum output values than those used in the current study.

CONCLUSIONS

1. A protocol using a combination of maximum output prescription (Dillon et al, 1998; Storey et al, 1998) and verification of aided loudness for high-level sounds was sufficient to ensure average RESRs did not exceed average LDLs by a substantial amount (<5 dB) for most participants (96%). Aided loudness aversiveness scores were below the 80th percentile for all but one participant.

2. There were no systematic relations between the RESR-LDL difference and the frequency of reported aided loudness problems as measured by the loudness questionnaires.

3. The initial setting of maximum output may be based on either unaided loudness discomfort measures or a prescriptive approach, but the latter approach is more efficient. Regardless of the method used, the initial setting should be validated at the time of the fitting to ensure that high-intensity sounds are not uncomfortably loud for the user.

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