Article

Verifying Loudness Perception After Hearing Aid Fitting

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During the verification phase of a hearing aid fitting, clinicians often want to assess the extent to which loudness perceptions for amplified sounds are similar to those typical of normal hearers. This type of verification calls for a criterion for "normal" loudness perception of sounds presented in a sound field. This research sought to answer several questions about the parameters of a valid "normal" criterion for a verification procedure using the Contour test of loudness perception. Loudness data were obtained from 30 listeners with normal hearing. Results indicated that a loudness growth function obtained with earphone listening is not an appropriate normative reference for hearing aid fitting verification. Instead, the normative data should be based on sound field listening.

Results also indicated that the same normative function could be used to assess both unilateral and bilateral fittings. Further, it is likely that the same normative function can be used for most frequency responses that are likely to be used in feasible fittings. Finally, it was found that a previously published normative function obtained using an automated test procedure was not faithfully replicated using a carefully executed fully manual test procedure. We concluded that, until a replicable normative function is established, practitioners will need to generate their own local norms to perform postfitting verification of loudness normalization.

Key Words: loudness, hearing, hearing aid, hearing test

Regardless of the precise prescription or method used to select, adjust, and fit amplification devices, there is universal agreement that restoration of more normal loudness perception is one of the important potential advantages of wide dynamic range compression hearing aids. Thus, even when the principal prefitting goal does not explicitly address loudness, it is logical for dispensers to aim for hearing aid fittings that will normalize loudness at least to the extent that soft environmental sounds are audible (but soft) after amplification, average environmental sounds are comfortable, and loud environmental sounds are loud (but not uncomfortable) after amplification.

In this article, we are advocating postfitting verification of loudness normalization for all hearing aid fittings, no matter what rules or approaches were used in the prefitting and adjustment protocol. More normal loudness perception is a basic need of persons with hearing impairment. Thus, the restoration of more normal loudness

perception is almost always an important consideration in evaluating the effectiveness of the final fitting.

Many clinicians and researchers agree that the verification phase of the fitting should include an assessment of the extent to which more normal loudness perception has been approximated (e.g., Cox, 1999; Mueller, 1999; Palmer, Mueller, & Moriarty, 1999; Valente and Van Vliet, 1997). However, there is not general agreement about how to incorporate aided loudness testing into a verification protocol. One approach is to measure a loudness growth function for amplified sounds. The obtained function can then be compared with an appropriate corresponding function for normal hearers (e.g., Grey and Dyrlund, 1996; Jenstad, Pumford, Seewald, & Cornelisse, 2000; Margolis, 1985). This article reports a study that explored several questions about the parameters of the normative function to be used in this type of loudness verification procedure. The long-term goal was to generate recommendations for using aided loudness testing in clinical verification protocols.

The primary research questions were as follows:

1. Is it appropriate to compare the aided loudness function measured in the sound field with a normative function that was derived from signals presented via earphones?
2. Can the same normative function be used for both unilateral and bilateral fittings?
3. Is the frequency response of the hearing aid likely to affect the aided loudness growth function?
4. Are manually administered loudness tests sufficiently accurate for fitting verification, or is it essential to control the testing procedure more rigorously by using an automated test?

Method

Test Stimulus

Several researchers have reported aided loudness growth functions obtained using relatively simple sounds such as warble tones or noise bands. These stimuli have the advantages of being readily available and brief. They have, in the past, yielded useful insights into fitting. However, it is doubtful that tests with simple signals will be appropriate to characterize the behavior of more recently developed hearing aids that use the complex signal processing that is now widely available.

Designers have been quick to capitalize on the potential advantages of sophisticated signal processing to address some of the persistent problems that continue to plague hearing aid users. As a result, newly engineered devices may incorporate processing strategies that attempt, for example, to improve communication in high noise situations, to seek and eliminate acoustic feedback, or to emulate certain cochlear functions. Because of the sometimes inscrutable action of these hearing aid circuits, it can be difficult to predict how a particular hearing aid will amplify typical environmental sounds.

One likely consequence of the intricacy of modern amplification strategies is that postfitting verification procedures can no longer rely on information obtained using amplified simple signals measured in a clinical environment to predict amplification results for complex signals experienced in real life. This occurs because the relationship between an amplified simple signal (such as warble tones) and an amplified complex signal (such as speech or other environmental sounds) will often be different from one instrument to another. Thus an aided loudness growth function for a warble tone will not yield an accurate, generalizable prediction of the aided loudness growth function that would be found for a more realistic signal such as speech.

Because of these considerations, the pragmatic approach at this time is to use realistic complex sounds as the test signal. For this research, we chose to use 5-s segments of continuous speech. Speech was chosen because it is the everyday stimulus that is most important to hearing aid wearers. A relatively long duration was selected because that is needed to activate processing changes in

FIGURE 1. Composite left ear and right ear audiograms of the 30 subjects. Bars, 1 *SD*.
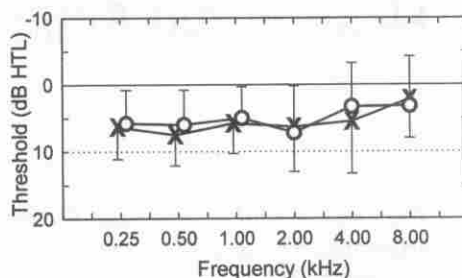
some types of hearing aids. Further, speech lasting several seconds is reasonably typical of everyday experience.

Loudness Test

The Contour test of loudness perception was used to generate loudness growth functions. In a previous publication (Cox, Alexander, Taylor, & Gray, 1997) the rationale for the design of this test was described. Also, this earlier publication provided normative data for a speech stimulus presented via earphones. The normative data were used for comparison in the current study.

The Contour test yields a level, for the test stimulus, for each of seven categories of loudness. The categories range from "very soft" to "uncomfortably loud." The stimulus is presented in an ascending manner beginning 5 to 10 dB above threshold and continuing to the uncomfortably loud level. Three or four ascending runs are administered for each stimulus (depending on response consistency), with a stimulus increment of 5 dB. The final level for each loudness category is the median of all the levels assigned to that category during the three or four test runs.

The standard test instructions are as follows:

1. The purpose of this test is to find your judgments of the loudness of different sounds.
2. You will hear sounds that increase and decrease in volume. You must make a judgment about how loud the sounds are. Pretend you are listening to the radio at that volume. How loud would it be?
3. After each sound, tell me which of these categories best describes the loudness.
4. Keep in mind that an uncomfortably loud sound is louder than you would ever choose on your radio no matter what mood you are in.

Subjects

Thirty adults served as subjects. Gender distribution was equal. Ages ranged from 19 to 46 years with a mean of 27 years. Figure 1 depicts their composite audiograms. None had previous exposure to loudness testing, and all reported subjectively normal hearing.

Procedure

There were eight listening conditions, and every subject received all conditions in a single test session. Table

**TABLE 1. Listening conditions for the investigation.**

Transducer	Stimulus
Earphone	Monaural broad band
	Binaural broad band
	Binaural low pass
	Binaural high pass
Sound Field	Monaural broad band
	Binaural broad band
	Binaural low pass
	Binaural high pass

1 summarizes the conditions. The order in which conditions were administered was counterbalanced across subjects.

Testing was carried out in a sound-treated room with ambient noise $\frac{1}{3}$-octave band levels of 19 dB SPL at 250 Hz, decreasing to 5 dB SPL at 8000 Hz. Sound field stimuli were presented using a Realistic Nova 18 100-W loudspeaker and originated at a 0° azimuth to the subject. The maximum linear output for speech (overall level) was 102 dB SPL in the sound field. For monaural sound field conditions, the nontest ear was plugged and muffed. It was empirically determined that the plug/muff combination typically resulted in attenuation of the stimulus to the nontest ear by 23 dB at 250 Hz, increasing to 52 dB at 4000 Hz. Earphone conditions were presented using ER-3A insert phones coupled to the ears with compressible foam plugs. The maximum linear output for speech (overall level) via earphone was 110 dB SPL in the HA-1 coupler.

To ensure that loudness judgments would not be influenced by spectrum differences, it was desirable that the speech spectrum at the eardrum should be the same for both transducers (earphone and loudspeaker). This was achieved using a $\frac{1}{3}$-octave equalizer to shape the spectrum of the sound field speech stimulus. Figure 2 depicts the calculated long-term average speech spectrum at the

FIGURE 2. Calculated long-term average spectra at the average eardrum for speech presented via earphone and in the sound field.
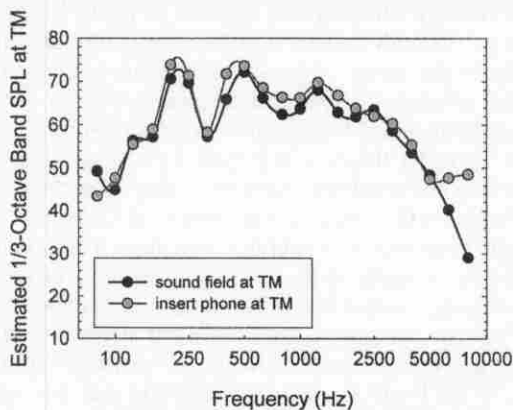
FIGURE 3. One-third octave band spectra for the three tape-recorded speech stimuli.
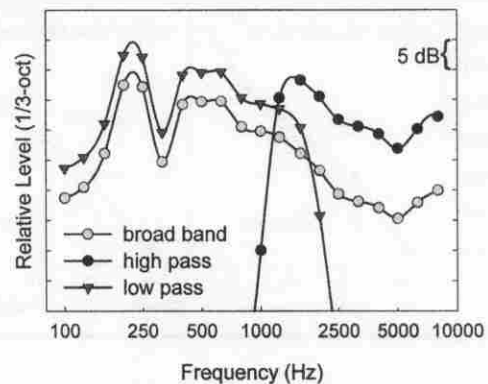
average eardrum for speech stimuli presented via loudspeaker and earphone. These were calculated by (1) adding the free field-to-eardrum transformation to the speech spectrum measured in the sound field and (2) adding the 2-cc coupler-to-eardrum transformation to the speech spectrum measured in the HA-1 coupler (Bentler and Pavlovic, 1989). For Figure 2, the two speech spectra were at equal overall levels before the transformations were added.

The stimulus for loudness testing was a 5-s sample of continuous speech drawn randomly from the test passages of the Connected Speech Test (CST; Cox, Alexander, & Gilmore, 1987). In the "broad-band" conditions, the speech was unfiltered. In the "high-pass" and "low-pass" conditions, the CST passages were filtered to retain high-frequency or low-frequency information, respectively. The cutoff frequency for filtering was 1500 Hz. All three types of speech stimuli were recorded on digital audiotape. Figure 3 depicts the $\frac{1}{3}$-octave band spectra for the three tape-recorded stimuli.

The testing protocol was identical to that used by Cox et al. (1997) with the following exception: The normative data reported by Cox et al. (1997) were obtained using a computer-driven test procedure in which the stimulus presentations were initiated using an audiometer under software control, and individuals responded by pressing a key on a response pad. In the present investigation, the Contour test was administered and scored manually. The participants responded orally to each stimulus presentation by saying the corresponding loudness category or category number.

Results and Discussion

The levels of seven loudness categories in each of eight listening conditions were obtained for each subject. Occasionally, the subject's uncomfortable level exceeded the maximum output of the equipment. In these cases, the level for category 7 (uncomfortably loud) was estimated as the maximum output plus 5 dB. This estimation was necessary in 6 of the 240 measurements of category 7.

The data were expressed in terms of sound pressure

FIGURE 4. Mean loudness growth functions for earphone and sound field stimuli.

FIGURE 5. Mean loudness growth functions for monaural and binaural stimuli.
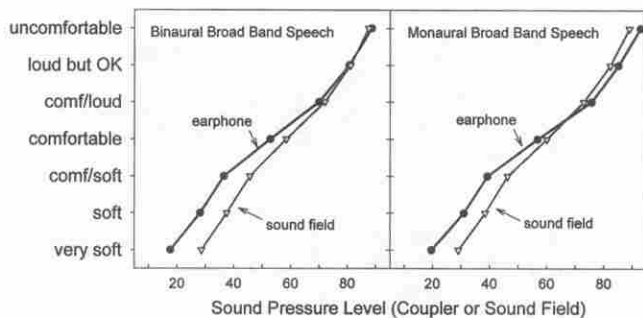
levels in the relevant calibration condition. Thus, for sound field stimuli, the levels corresponding to each loudness category were measured in the sound field at the test position with the subject absent. For earphone stimuli, the levels corresponding to each loudness category were measured in the HA-1 coupler, with the ER-3A earphone attached to the coupler via the compressible foam earplug.

## Loudness Growth in Earphone and Sound Field Listening

The first research question concerned the validity of comparing an aided loudness growth function obtained in sound field listening with a normative loudness growth function obtained under earphones. This study allowed us to address that question by comparing loudness growth functions obtained in both sound field and earphone listening when other, potentially confounding, variables were controlled.

Figure 4 depicts the mean loudness growth functions for earphone and sound field stimuli. Data are given for both monaural and binaural listening. Both panels show that the loudness growth function was steeper for sound field listening than for earphone listening. "Very soft" occurred at a higher level in the sound field than under earphones. This could be due, in part, to the higher ambient noise level for sound field listening. In binaural listening, the two functions merged at the "loud but OK" category, and the "uncomfortable" levels were about the same for both transducers. In monaural listening, the functions crossed at a loudness between "comfortable" and "comfortable but slightly loud", and the "uncomfortable" level was about 5 dB lower in the sound field than under the earphone.

Multivariate analysis of variance confirmed the presence of these effects ($p < .05$):

- In binaural listening, each of the first four loudness categories (very soft through comfortable) was found at a significantly lower level under the earphone than in the sound field. Loudness categories 5 through 7 (comfortable but slightly loud through uncomfortable) were not significantly different for the two transducers.

- In monaural listening, every loudness category yielded a significant difference when earphone data were
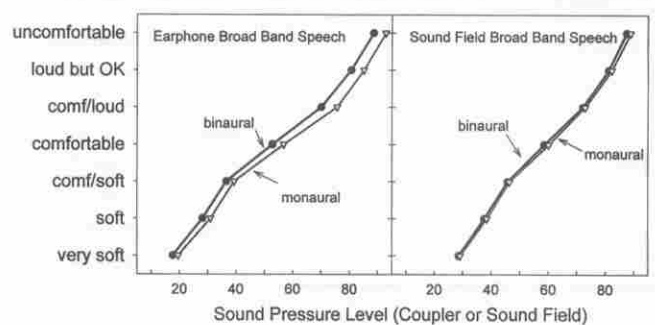
compared with the corresponding sound field data: for loudness categories 1 through 4, the earphone level was lower than the sound field level. For loudness categories 5 through 7, the earphone level was higher than the sound field level.

This pattern of results indicates that loudness growth in sound field listening is significantly different from that in earphone listening. When both types of signals are calibrated in the usual way, as in this study, speech at soft and conversational levels (less than ~70 dB SPL) tends to appear louder when presented under earphones than when heard in the sound field. At higher levels, this pattern tends to reverse, but the loudness relationship between the two transducers is partly dependent on whether the subject is listening monaurally or binaurally.

Clinical Implication. Based on these results, we conclude that it would not be appropriate to evaluate aided loudness perception by comparing it to an earphone-generated normative function. Verification of aided loudness perception should be performed with reference to a normative loudness growth function measured in sound field listening conditions.

Loudness Growth in Binaural and Monaural Listening

In recent years, about 68 of every 100 hearing aid fittings in the United States are bilateral, and 32 are unilateral (Skafte, 2000). It is reasonable to ask whether the same normative function can be used to verify loudness perception for both unilateral and bilateral fittings. Figure 5 illustrates the mean loudness growth functions for binaural and monaural listening. Data are shown for earphone-generated and loudspeaker-generated stimuli.

First, consider the data in Figure 5 (left) showing loudness growth for earphone listening. There is a clear separation between the binaural and monaural functions, indicating the presence of binaural summation. There is a trend for the amount of binaural summation to increase with increasing sound level. The largest summation was 5.6 dB for the category comfortable but slightly loud. On average, a given category of loudness was found at a level 3.75 dB lower for binaural listening than for monaural listening. Multivariate analysis of variance revealed

that the mean binaural-monaural difference was statistically significant ($p < .005$) in every loudness category.

It has been shown that the amount of binaural summation observed in loudness tests depends partly on the psychophysical measurement procedure (Hawkins, Prosek, Walden, & Montgomery, 1987). The results reported above are consistent with previous work using categorical loudness comfort judgments and a speech stimulus presented via earphones (Christen, 1980).

Now consider the loudness growth functions obtained for sound field listening (Figure 5, right). The trend for the binaural function to lie to the left of the monaural function is much less obvious than in earphone listening. In fact, there is an average difference of only 1.06 dB between the binaural and monaural functions. This difference is statistically significant overall ($p = .001$). However, when tested at each loudness category, the difference between monaural and binaural levels reached the $p < .05$ level of significance only for categories 2, 4, and 6.

These results showing very small binaural summation are somewhat at variance with studies that have used a different loudness measurement method in the sound field. For example, Dermody and Byrne (1975) reported 3 to 5 dB of binaural loudness summation in the sound field when the task was matching the loudness to a comparison stimulus. The explanation for these differences probably can be found in the effect of the internal criterion provided by a comfort matching task versus that of the external criterion used in a traditional loudness matching task (Melnick, 1967).

The present investigation determined that the difference in comfort between binaurally and monaurally perceived speech is considerably greater when listening under earphones than when listening in the sound field. This outcome corroborates the report by Hawkins et al. (1987) for individuals listening to sound field stimuli using a comfort criterion. They observed an average binaural summation of only 0.93 dB when subjects judged loudness discomfort levels for monaural and binaural stimuli presented in a sound field.

Clinical Implication. Because the binaural and monaural loudness growth functions were so similar for sound field listening, it seems reasonable to use the same normative loudness growth function for verification of loudness perception in both unilateral and bilateral types of hearing aid fitting.

Loudness Growth for Flat, Low-Pass, and High-Pass Frequency Responses

Normative loudness growth data usually are obtained using natural stimuli that have not been altered in the frequency domain. However, most hearing impairments are not equal across frequency, and hearing aid wearers typically listen to sounds that have been weighted in each frequency region in proportion to the extent of their hearing loss. It is appropriate, therefore to consider whether

FIGURE 6. Mean loudness growth functions for broad-band speech and for high-pass filtered and low-pass filtered speech. All stimuli were presented binaurally.
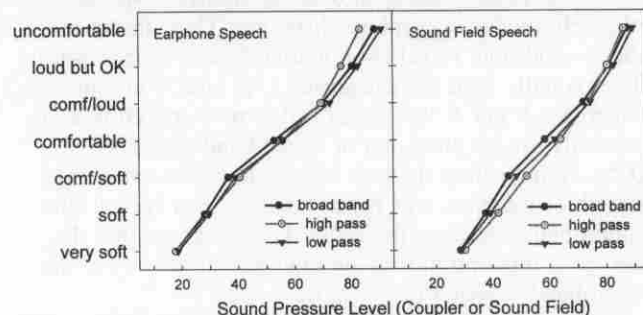
the frequency weighting applied by the amplification system might have an influence on the loudness growth function for speech. This was addressed in the present study by comparing loudness growth functions for broad-band speech with those obtained for low-pass filtered and high-pass filtered speech. All stimuli were presented binaurally.

Figure 6 depicts the loudness growth functions for these three stimuli. Data are given separately for earphone and sound field listening. Consider the data showing the loudness growth functions in the sound field (Figure 6, right). Compare the function for broad-band speech with that for low-pass speech. The two functions are essentially parallel, with the low-pass function ~2 dB to the right of the broad-band function. This indicates that, at a given SPL, the low-pass speech was judged to be slightly less loud than the broad-band speech. This finding is consistent with data on summation of loudness across bandwidth, which would predict that the narrower bandwidth stimulus should be less loud even when the sound pressure levels are equal (Zwicker, Flottorp, & Stevens, 1957). The effect is statistically significant ($p < .05$, multivariate analysis of variance) for all loudness categories except category 1 (very soft).

Now, again in the right panel of Figure 6, compare the loudness growth function for broad-band speech with that for high-pass speech. These two functions do not appear to be essentially parallel: the two functions are separated for the lower loudness categories but merge at the two highest categories. Statistical analysis (multivariate analysis of variance) supported this observation, revealing that the two stimuli produced significantly different levels for each of the five lowest loudness categories ($p < .05$) but not for the two highest loudness categories. In other words, the loudness of high-pass speech was less than that of broad-band speech when comparisons were made at equal sound pressure levels less than ~80 dB SPL. At higher levels the high-pass speech "caught up" with the broad-band speech and appeared equally loud.

The left panel of Figure 6 illustrates the loudness growth functions for broad-band, low-pass, and high-pass speech when the stimuli were presented via earphones. The relationship between broad-band and low-pass speech

was identical to that seen in sound field listening. In contrast, the relationship between broad-band speech and high-pass speech appears slightly different for earphone and sound field listening in that the high-pass speech was relatively louder in earphone listening. Thus, in the earphone condition, broad-band and high-pass speech were about equally loud for categories 1, 2, and 5. In loudness categories 3 and 4, the level of high-pass speech was significantly greater than that of broad-band speech ($p <$ .005). Approaching the two highest loudness categories, growth of loudness was faster for high-pass speech (the same trend as seen in the sound field data), so that the high-pass function moved significantly to the left of the broad-band function ($p <$ .005).

Clinical Implication. Although the general trends were the same, the details of the results were slightly different for earphone and sound field listening. Because hearing aids are only used for sound field listening, application of these results to hearing aid verification procedures should be based on the data observed in sound field listening. The frequency response manipulations used in this study simulated narrowing the hearing aid's bandwidth toward low or high frequencies. We did not assess the effects, if any, of frequency response slope or irregularities. Based on the outcomes depicted in Figure 6, two conclusions are suggested regarding the relationship between loudness perception and hearing aid frequency response:

- If the high-frequency range of the hearing aid is relatively limited so that the high-frequency components of speech are reduced, the loudness of speech will be slightly less than that in the normative data, but the shape of the loudness growth function will not be altered. This effect might reduce the level of each loudness category, but not more than a couple of decibels. Thus, it seems reasonable to rely on the normative loudness growth function for broad-band speech in this type of fitting.

- If the low-frequency range of the hearing aid is limited such that the instrument produces only high-frequency speech cues, *and* the low-frequency cues are not supplied in any other way, such as via a vented earmold, there is evidence that the loudness growth function is substantially affected. Compared with broad-band speech, the loudness of high-pass speech appears to grow more slowly through the lowest loudness categories and then more quickly through the highest loudness categories. This observation probably would impact very few hearing aid fittings because the importance of providing audibility across a wide frequency range is well known among hearing aid dispensers and a fitting that provides access only to high frequencies is not likely to occur.

Accuracy of Manually Administered Loudness Tests

Loudness verification procedures attempt to assess the extent to which loudness perceptions are normalized in aided listening. Such procedures must inherently include a comparison to a normative standard. In other words, the

FIGURE 7. Mean loudness growth function from this study compared with the corresponding function from Cox et al., 1997 (norms).
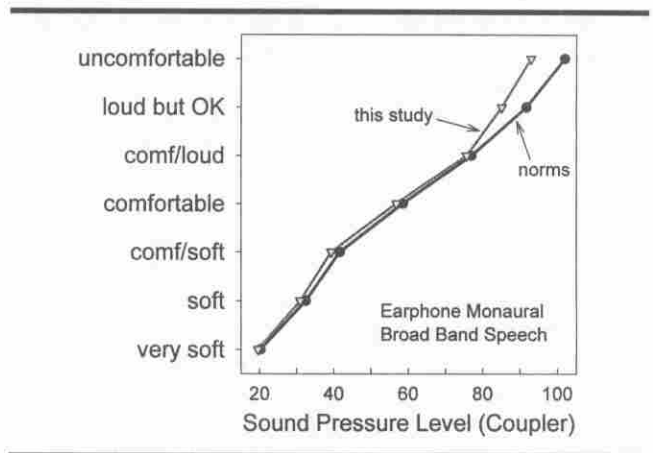

clinically measured loudness growth function must be compared with a norm. Most tests of this sort rely on published normative data. However, it is well known that the results of loudness perception testing are susceptible to the influence of testing variables (e.g., Cox et al., 1997; Ricketts and Bentler, 1996; Ward and Lockhead, 1970). One approach to this problem is to rigorously control the test variables through computer-driven administration. However, this increases the hardware and software demands of the procedure and places it effectively beyond the capabilities of many dispensers. Thus, it is reasonable to ask whether careful manual administration of the loudness test could result in sufficient control over testing variables so that comparisons with published norms could be feasible and valid.

This matter was addressed in this investigation by attempting to replicate, using manual test administration, the normative loudness growth function reported by Cox et al. (1997) for monaural, broad-band speech presented via the ER-3A earphone. The normative function derived by Cox et al. was obtained using a software-driven test procedure and 45 subjects. The clinician typed the SPL for the first stimulus presentation, and the software administered the rest of the test for that stimulus: presenting the sounds, accepting the responses provided by the subject on a small handheld keypad, incrementing and decrementing the stimulus levels, determining when to conclude the test, and reporting the result.

All of the data in the present study were collected by a different tester, using different equipment, and different subjects from those in the Cox et al. study. The testing was controlled manually, and the attempt was made to precisely replicate the test procedures used several years previously by Cox et al. Figure 7 depicts the mean loudness growth function from the present study compared with the corresponding function from Cox et al. (1997). The two functions are almost identical for loudness categories 1 through 5. However, results in the present study for loudness categories 6 and 7 clearly deviate from those

FIGURE 8. Mean loudness growth functions for 10 participants tested manually and also using a software-driven automated procedure.
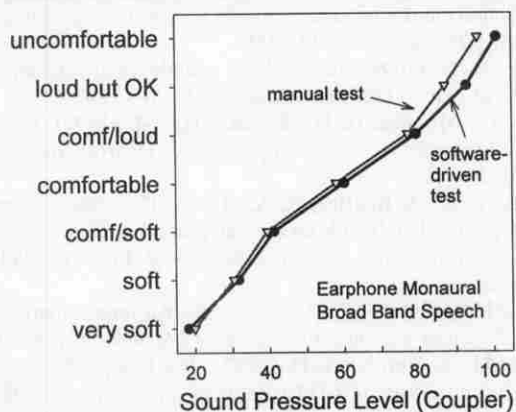
for the earlier study: Both the loud but OK and the uncomfortable levels were lower in the present study than in the earlier study. Univariate analysis of variance confirmed that there were no significant differences between the functions for the five lower loudness categories and that the differences were statistically significant ($p < .02$) for the two higher categories.

These data revealed that our attempt to replicate the published norms was not fully successful. Careful examination and comparison of the procedures used in the two studies produced only two potential culprits for the differences in outcome: (1) in the present study, participants responded by orally reporting the number (one through seven) corresponding to his/her chosen loudness category, whereas in the earlier study the response was registered by pressing the appropriate key on a small keypad. It seemed unlikely that this could have affected the outcome only for two loudness categories; and (2) in the present study, the nominally 5-s duration speech stimulus was presented by manually pressing the audiometer button for a count of five and then releasing it, whereas in the earlier study the stimulus duration was timed by the software. Subsequent examination suggested that the actual duration of the stimulus in the present study probably varied from 5 to 7 s. It is possible that this duration difference was immaterial to the loudness for low and comfortable levels but affected the responses at higher levels.

To examine the assumption that the differences seen in Figure 7 were due to a subtle procedural variation, 10 of the participants from the present study were retested using the software-driven test procedure used by Cox et al. The mean loudness growth functions obtained for these 10 individuals in the original manual test and in the software-driven test are depicted in Figure 8. The pattern in Figure 8 is identical to that seen in Figure 7: the two functions are very similar for the five lower loudness categories but separate for the two higher categories with the manual test eliciting the lower levels. It should be noted that the differences between manual and automated testing data in Figure 8 were not statistically significant.

However, with only 10 subjects, the power of this analysis was low. Despite the absence of statistical confirmation, the striking resemblance between the patterns shown in Figures 7 and 8 supports the conclusion that the difference between the results of this study and the Cox et al. (1997) norms can be attributed to a procedural variation. Further research will be necessary to determine the exact nature of the variation.

Clinical Implication. These results suggest that if we want to verify normalization of loudness perception by comparing clinically measured loudness data with a published norm, it will be necessary to use a clinical loudness testing protocol that is automated in some respects to ensure comparable data. Further research is necessary to develop an appropriate protocol and its associated norm.

At the present time, manual (nonautomated) administration of the Contour Test can still be used to perform postfitting verification of loudness normalization. However, each testing clinician will need to generate his/her own normative reference using a consistent clinical protocol and a sample of normal-hearing subjects.

Conclusions

The results of this investigation support the following recommendations about postfitting verification of loudness normalization.

1. Until it can be established that a published norm can be replicated by other testers, each clinician should generate his/her own normative data for use in loudness verification procedures.
2. It would be reasonable to base the test protocol on the one used in this study; however, other protocols could be equally useful. Locally generated norms should be based on a sample of at least 15 normal-hearing individuals who do not have previous experience with loudness perception testing.
3. Postfitting loudness verification norms should reflect binaural listening to a stimulus generated in a sound field from a 0° azimuth. It is not appropriate to use earphone-generated stimuli to obtain the norms.
4. Both unilateral and bilateral hearing aid fittings can be assessed using the norm for binaural listening.
5. A normative function obtained using broad-band speech will be appropriate for assessing fittings with most feasible frequency responses. However, an unusual fitting such as one that allows only high-frequency sounds to be heard might produce a different loudness growth pattern.

Despite these recommendations, we recognize that many practitioners do not have the resources necessary to generate their own norms for postfitting verification of aided loudness perception. Determination and publication of a replicable normative function for this purpose and guidelines for its use should be a high priority for future research.

Acknowledgments

References

Bentler, R. A., & Pavlovic, C. V. (1989). Transfer functions and correction factors used in hearing aid evaluation and research. *Ear and Hearing, 10,* 58–63.

Christen, R. (1980). Binaural summation at the most comfortable loudness level. *Australian Journal of Audiology, 2,* 92–98.

Cox, R. M. (1999). Five years later: An update on the IHAFF fitting protocol. *Hearing Journal, 52*(9), 10–18.

Cox, R. M., Alexander, G. C., & Gilmore, C. A. (1987). Development of the Connected Speech Test (CST). *Ear and Hearing, 8*(Suppl.), 119S–126S.

Cox, R. M., Alexander, G. C., Taylor, I. M., & Gray, G. A. (1997). The Contour test of loudness perception. *Ear and Hearing, 18,* 388–400.

Dermody, P., & Byrne, D. (1975). Loudness summation with binaural hearing aids. *Scandinavian Audiology, 4,* 23–28.

Grey, H., & Dyrlund, O. (1996). Putting loudness scaling to work: Moving from theory to practice. *Hearing Journal, 49*(3), 49–54.

Hawkins, D. B., Prosek, R. A., Walden, B. E., & Montgomery, A.A. (1987). Binaural loudness summation in the hearing impaired. *Journal of Speech and Hearing Research, 30,* 37–43.

Jenstad, L. M., Pumford, J., Seewald, R. C., & Cornelisse, L. E. (2000). Comparison of linear gain and wide dynamic range compression hearing aid circuits II: Aided loudness measures. *Ear and Hearing, 21*(1), 32–44.

Margolis, R. H. (1985). Magnitude estimation of loudness: III. Performance of selected hearing aid users. *Journal of Speech and Hearing Research, 28*(3), 411–420.

Melnick, W. (1967). Comfort level and loudness matching for continuous and interrupted signals. *Journal of Speech and Hearing Research, 10,* 99–109.

Mueller, H. G. (1999). Just make it audible, comfortable, and loud but okay. *Hearing Journal, 52*(1), 10–16.

Palmer, C., Mueller, H. G., & Moriarty, M. (1999). Profile of aided loudness: A validation procedure. *Hearing Journal, 52*(6), 34–42.

Ricketts, T. A., & Bentler, R. A. (1996). The effect of test signal type and bandwidth on the categorical scaling of loudness. *Journal of the Acoustical Society of America, 99*(4), 2281–2287.

Skafte, M. D. (2000). The 1999 hearing instrument market—The dispenser's perspective. *Hearing Review, 7*(6), 8–40.

Valente, M., & Van Vliet, D. (1997). The Independent Hearing Aid Fitting Forum (IHAFF) Protocol. *Trends in Amplification, 2*(1), 6–35.

Ward, L. M., & Lockhead, G. R. (1970). Sequential effects and memory in category judgments. *Journal of Experimental Psychology, 84*(1), 27–34.

Zwicker, E., Flottorp, G., & Stevens, S. S. (1957). Critical band width in loudness summation. *Journal of the Acoustical Society of America, 29*(5), 548–557.

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