A combined comfort and audibility index for hearing aid fitting and evaluation.

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Abstract

An "adjusted audibility index" is described, based on thresholds and measured comfortable levels for listeners with impaired hearing, and on the measured output levels of hearing aids fit to the listeners' hearing loss. The index is based on the concept of a trade-off between comfort for loud sounds and intelligibility for soft sounds. The index predicts preferred volume settings and relative speech intelligibility at the preferred volume setting from acoustic measures of the aid. Actual preferred speech perception scores, and preference data from clinical trials of wide dynamic range compression and a new ADRO™ digital hearing aid were in accord with the predictions of the adjusted index, demonstrating its potential utility for fitting and evaluation. The ADRO™ processing scored higher on speech intelligibility tests at low input levels, and on preferences for a wide range of environmental sounds. These results show improvements in both comfort for loud sounds and audibility of soft sounds. Measurements for eight high-end commercial hearing aids fit to the manufacturers' recommendations also demonstrated a wide range of adjusted audibility indices, and hence a wide range of trade-offs between comfort and audibility. ADRO™ performed at the high end of this range.

Background

Hearing aid fittings involve a trade-off between comfort for loud sounds and audibility for soft sounds. As the hearing loss becomes more severe, the listener's dynamic range is reduced and it becomes more difficult to achieve a good balance between comfort and audibility. For wide dynamic range compression, parameters such as the compression ratio and compression threshold affect the nature of this trade-off. A different balance between comfort and audibility is possible with a new amplification strategy which independently sets Comfort Targets and Audibility Targets so that both comfort and audibility can be maximized for the individual. This new amplification scheme is called ADRO™ [1, 2]. In order to compare WDRC and ADRO™, a combined comfort and audibility index was developed.

The well-known Speech Intelligibility Index (SII) captures the audibility component, but does not take into account the comfort of the listener [3]. A new "adjusted audibility index" is proposed that combines a speech weighted audibility index similar to the SII for speech at 50 dB SPL with a measure of discomfort for multi-talker babble at 85 dB. The SII requires knowledge of the listener's hearing thresholds. The measure of comfort requires knowledge of comfortable listening levels across frequency, and is used to predict the preferred volume setting for the listener from the measured output of the hearing aid in a hearing aid test box.

Fitting Method

The adjusted index was developed and tested using very detailed measurements of three hearing aid fittings for two listeners who were participating in clinical trials comparing ADRO™ and WDRC amplification schemes in the same hearing aid processor [4]. The hearing thresholds for the two listeners are shown in Table 1. The two listeners were chosen because their hearing losses were representative of the larger group. Listener 1 had a gently sloping hearing loss with a pure-tone average of 33 dB HL. Listener 2 had a steeply sloping hearing loss with a PTA of 58 dB.

The ADRO™ hearing aid was programmed to produce noise stimuli with 1/6 octave bandwidth at calibrated output levels. These stimuli were used to measure in-situ thresholds, comfortable levels and very loud levels at eleven frequencies from 125 to 6000 Hz.

Thresholds were also measured using conventional methods and an audiometer. Three hearing aid fittings were produced for each of the two listeners: A linear fit according to the NAL-RP prescription [5], together with a frequency-specific maximum output limit; A WDRC fit according to the NAL-NL1 prescription [6]; and an ADRO™ fitting using the method described by Martin et al. [1].

Table 1. Hearing loss in dB HL for the listeners.

	Listener 1	*Listener 2*
250 Hz	20 dB	45 dB
500 Hz	20 dB	50 dB
1000 Hz	30 dB	60 dB
2000 Hz	50 dB	65 dB
4000 Hz	85 dB	75 dB
8000 Hz	90 dB	105 dB

Acoustic Measurement Method

For each listener's three fittings, the experimental setup shown in Figure 1 was used to measure the output of the hearing aid in 1/3 octave bands.
The input signal was a 30 second sound sample of recorded speech and/or noise. The long-term average

Figure 1. Setup for acoustic measurement of hearing aid output levels.

spectrum and percentile measures were calculated and averaged using the B&K sound level meter. Seventeen different input signals were recorded for each fitting in total: Male and Female speakers at 50, 60, and 70 dB SPL; a one-octave band of noise at 1 kHz and 55 dB SPL; eight-talker babble and traffic noise at 55 and 85 dB SPL; Female speaker at 60 dB SPL in each of the 3 noise signals at 55 dB SPL; and Female speaker at 75 dB SPL in quiet and in eight-talker babble and traffic noise at 85 dB SPL.

Example measurement results are shown in Figures 2 to 5. Each figure shows the measured long-term average output levels and percentiles compared to the listener's threshold, comfortable, and uncomfortable level measures with black symbols and lines. The percentile measures shown as thinner pink lines are for 98%, 90%, 70%, 50 %, 30%, and 10%. The thicker red line shows the measured Leq values. The threshold, comfortable and uncomfortable levels shown in the figures are for Listener 2.

The measurements provided an enormous amount of data which were useful in understanding the differences between the different fittings and amplification strategies. The most useful measurement conditions were for speech in quiet at 50 dB SPL, and for speech in noise at high levels.

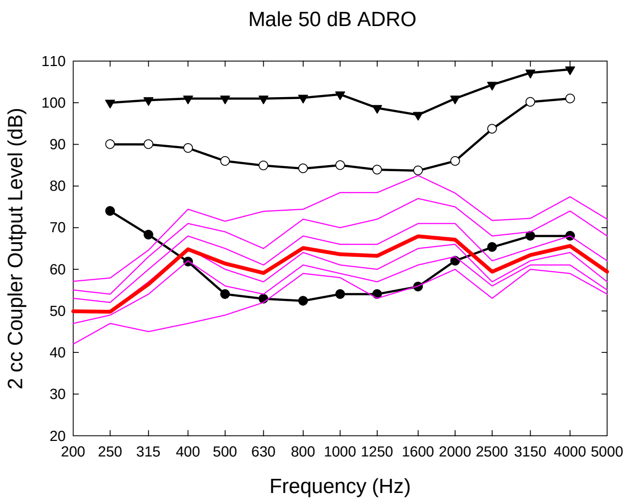

Figure 2. ADRO™ hearing aid output levels for a male speaker at 50 dB SPL.

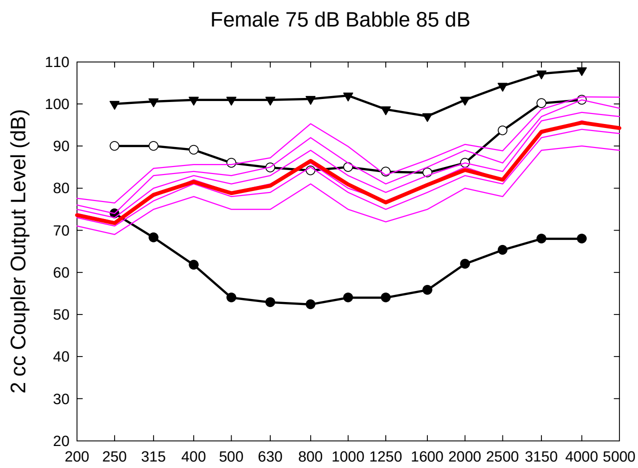

Figure 4. ADRO™ hearing aid output levels for a female speaker at 75 dB in babble at 85 dB SPL.

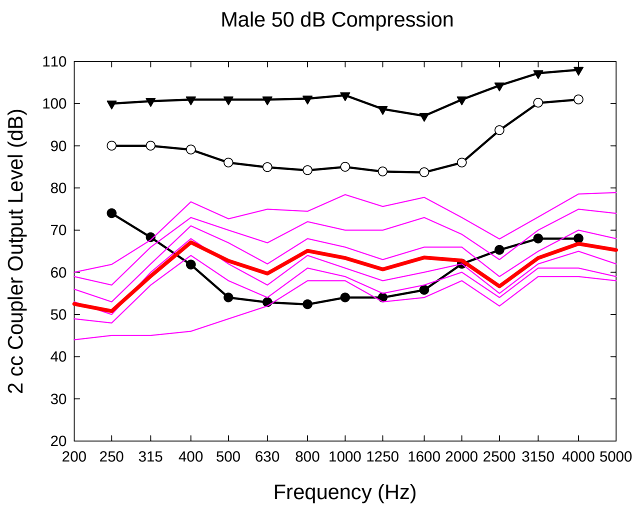

Figure 3. WDRC compression hearing aid output levels for a male speaker at 50 dB SPL.

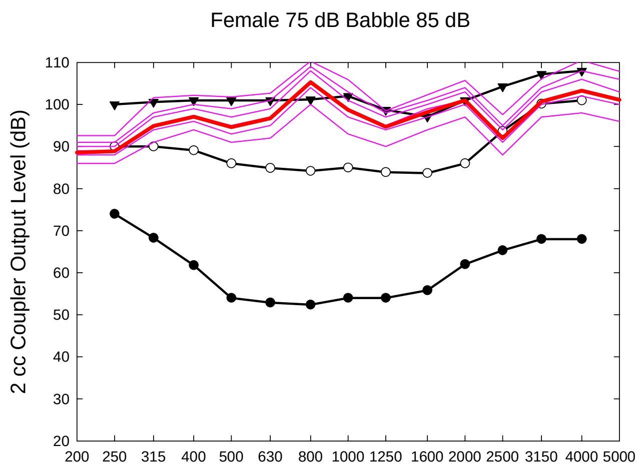

Figure 5. WDRC hearing aid output levels for a female speaker at 75 dB in babble at 85 dB SPL.

Adjusted Audibility Index Calculations

The audibility component of the adjusted index was calculated using the basic formula from the speech intelligibility index [3], applied to the 50 dB SPL speech measures in quiet.

Audibility Index = $\Sigma w_i L_i$

where w_i is the speech intelligibility index weight at frequency i, and L_i is the measured difference between the listener's threshold and the 98% hearing aid output level at frequency i, subject to a maximum of 30 dB. The resulting index has a range from zero to one, from unintelligible to completely intelligible. The audibility index is equivalent to the red-shaded area shown in Figure 6, with appropriate weighting at each frequency. The audibility index was averaged over both listeners, and both male and female speakers.

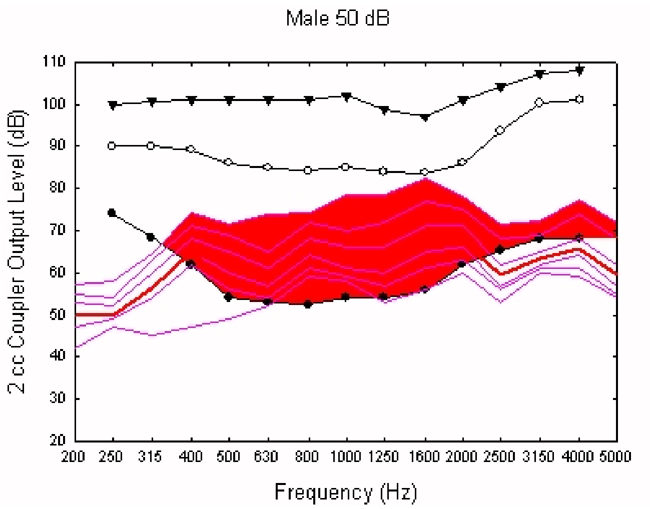

Figure 6. The audibility index represents a weighted sum of the red shaded area of the speech spectrum.

The comfort component of the adjusted index was calculated as the amount by which the 98% long term spectrum for loud sounds exceeded the comfortable levels, averaged over the fourteen 1/3 octave frequencies. Figure 7 shows an example of the part of the spectrum that would contribute to the comfort index. The comfort index is a value in dB, and is an estimate of the amount by which a listener would reduce the gain of the hearing aid in order to keep loud sounds comfortable. The comfort index was averaged over both listeners, and all signals that included noise at 85 dB SPL.

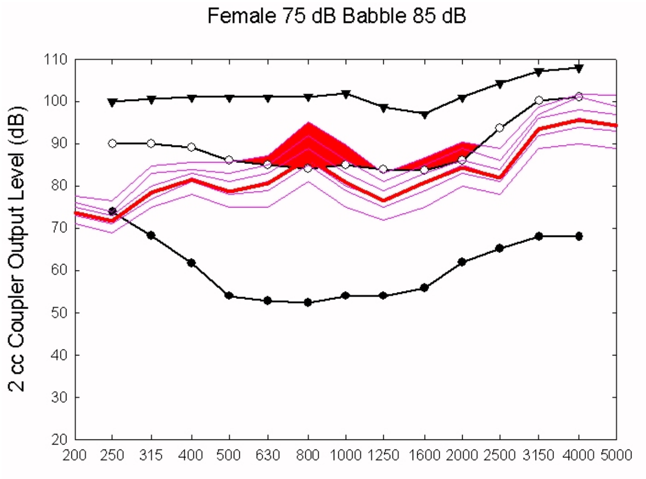

Figure 7. The comfort index is the average dB value of the sound spectrum above the comfort levels.

The adjusted audibility index was calculated by combining the audibility and comfort indices in the following formula:

Adjusted index = audibility index – comfort index / 30

the division by 30 is to convert the comfort index from a dB value to a dimensionless number with a 30 dB range as in the calculation of the audibility index.

Predicted preferred volume settings were compared with actual preferred volume settings from clinical trials of linear, compression, and ADRO™ hearing aids. Predicted speech perception scores were also compared with actual speech perception scores from the same clinical trials. The predictions of the adjusted audibility index were in agreement with the results from the trials, demonstrating the potential usefulness of the index for both fitting and evaluation of hearing aids.

Results

The audibility, comfort, and adjusted audibility indices calculated for the three hearing aid amplification schemes are shown in Table 2. Although they have been calculated for two listeners only, they can be used to make some qualitative predictions about the relative scores that hearing impaired listeners will achieve with the three amplification schemes.

Table 2. Calculated Indices.

	Audibility Index	*Comfort Index (dB)*	*Adjusted Index*
ADRO™	0.54	2.2	0.47
WDRC	0.59	10.9	0.23
Linear	0.49	3.8	0.36

If the assumptions underlying the calculations are correct, the audibility index predicts that all three hearing aids would perform similarly on a speech perception task with 50 dB SPL input level at the prescribed volume and gain settings. The comfort index predicts that the aid programmed for WDRC would need to be turned down by about 10 dB, the linear aid by about 4 dB, and the ADRO™ aid by about 2 dB in a noisy environment at 85 dB SPL. Following the volume control adjustment, the revised speech perception scores at 50 dB SPL would be greatest for ADRO™, followed by the linear system with frequency specific maximum output limits, and then the WDRC scheme.

Two clinical trials have been carried out, comparing ADRO™ with WDRC in an ITE and a BTE device [7], and comparing a linear hearing aid with ADRO™ [1].These studies have confirmed that ADRO™ produces the higher scores than either WDRC or Linear amplification for 50 dB SPL input levels when the aids are set to the listeners' preferred volume settings. They also showed that ADRO™ produces a high quality signal of comfortable loudness which was preferred to WDRC in 74% of the situations tested [7].

The adjusted audibility index calculations were also made with eight top of the range commercial hearing aids fit to the same two hearing losses in Table 1, according to the recommendations of the manufacturers. The results for the audibility index at 50 dB SPL input level ranged from 0.09 to 0.64. The values for the comfort index ranged from 0 to 8.7 dB, and the adjusted audibility index ranged from 0.09 to 0.52. On the basis of this calculation seven out of the eight top-end commercial hearing aids produced a less favourable balance between comfort and audibility than the ADRO™ amplification scheme.

Conclusions

The measurement of hearing aid output spectra for multiple hearing aids and amplification schemes indicated a wide variation in the trade-offs chosen by hearing aid manufacturers for compression amplification schemes, and predicted that the ADRO™ amplification scheme would result in a more favourable trade-off than a linear amplification scheme and a WDRC scheme implemented on the same hearing aid. This prediction was verified in three sets of clinical trial data.

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