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

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The Adjusted Audibility Index

Audibility – Discomfort = Adjusted Audibility Index

Successful hearing aid fittings find a good balance between audibility for soft sounds and comfort for loud sounds.

Background: The goal of a hearing aid fitting is to make sounds louder, but if they become too loud, the listener will turn down the volume. Therefore, any prediction of benefit from a hearing aid should take into account both the audibility of soft sounds and the comfort of loud sounds. **The "adjusted audibility index"** is based on the concept of a trade-off between comfort for loud sounds and intelligibility for soft speech. The calculations take into account measured thresholds and comfortable levels for listeners with impaired hearing, and measured output levels of hearing aids fit to the listeners' hearing loss. The index predicts preferred volume setting and relative speech intelligibility at the preferred volume setting of the aid.

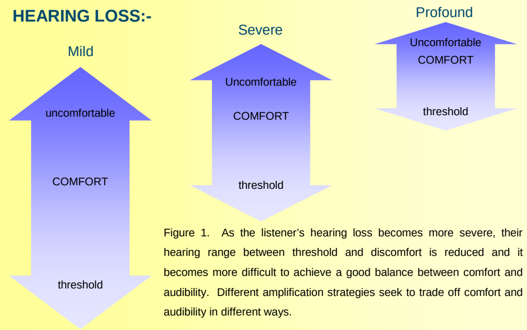
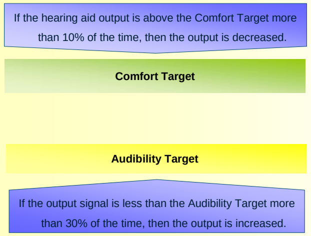


Figure 1. As the listener's hearing loss becomes more severe, their hearing range between threshold and discomfort is reduced and it becomes more difficult to achieve a good balance between comfort and audibility. Different amplification strategies seek to trade off comfort and audibility in different ways.

The gain of a **linear amplification** scheme determines audibility of soft sounds, and a limiting scheme such as clipping or automatic gain control determines the comfort of loud sounds. For **wide dynamic range compression**, parameters such as the compression ratio and compression threshold affect the nature of this trade-off. A new amplification strategy, **ADRO™**, independently sets comfort and audibility targets so that both comfort and audibility can be maximized for the individual.

Figure 2. Representation of ADRO™ Processing.



ADRO™ processing

- Comfort and audibility targets are set within the listener's dynamic range.
- In 64 frequency bands, comfort and audibility rules keep the hearing aid output within the fitted dynamic range.
- The maximum output rule acts instantaneously to control sudden loud sounds that would otherwise exceed the Maximum Output Level.
- The maximum gain rule keeps very soft sounds from becoming too loud.

Hearing aid fittings

Thresholds were measured for two listeners using conventional methods. Three hearing aid fittings were produced for the ear with the lower pure-tone average thresholds for each of the two listeners: A linear fitting according to the NAL-RP prescription together with a frequency-specific maximum output limit; A WDRC fitting according to the NAL-NL1 prescription[1]; and an ADRO™ fitting. The ADRO™ hearing aid was programmed by measuring in-situ thresholds, comfortable levels and very loud levels at eleven frequencies from 125 to 6000 Hz with 1/6 octave narrow band noise at calibrated output levels.

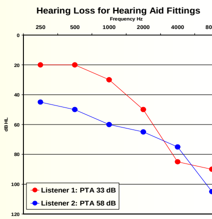


Figure 3. Hearing loss in dB HL for the listeners.

Acoustic Measurement Method

Hearing aid output levels were measured for the three fittings for each listener using the experimental setup shown in Figure 4. The input signals were 30 seconds of recorded speech at 50 dB SPL and 30 seconds of speech at 75 dB SPL in noise at 85 dB SPL. Long-term average spectrum and percentile measures were calculated and averaged in 1/3 octave bands using the B&K sound level meter.

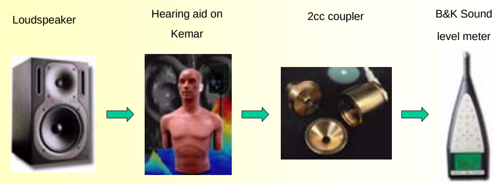


Figure 4. Set-up for acoustic measurement of hearing aid output levels.

Results

Example measurement results are shown below in Figure 5. The threshold, comfortable and uncomfortable levels for listener 1 are shown in the graphs below with black lines and symbols. Each graph shows the measured long-term average output levels and percentiles compared to the listener's threshold, comfortable, and uncomfortable level measures. 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 two left panels show the ADRO™ processing and the two right panels show WDRC processing. Note that the ADRO™ and WDRC graphs for speech at 50 dB SPL are similar, but the WDRC graph for 75 dB speech in babble at 85 dB SPL has higher output levels than the corresponding ADRO™ graph.

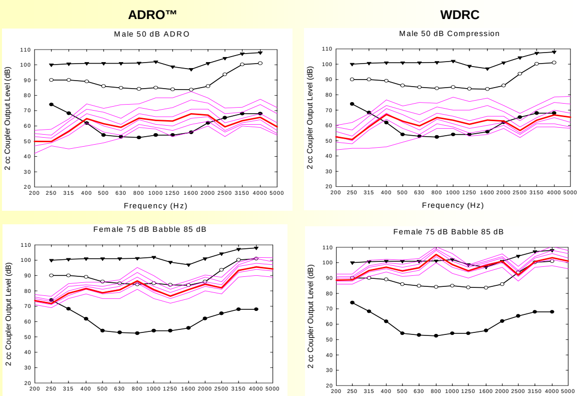


Figure 5. Measured long term average output levels and percentiles compared to the listener's threshold, comfortable and uncomfortable level measures.

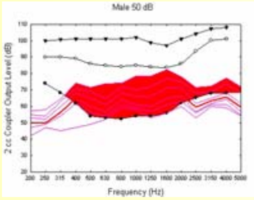


Figure 6. The audibility index represents a weighted sum of the red shaded area of the speech spectrum.

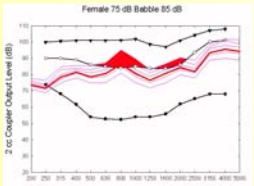


Figure 7. The comfort index is the average dB value of the sound spectrum above the comfort levels.

Calculations

The audibility index for soft sounds was calculated using the speech intelligibility index applied to the 50 dB SPL speech measures in quiet:

$$\text{Audibility Index} = \Sigma\, w_i\, L_i$$

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 in Figure 6. The audibility index was averaged over both listeners, and for a male and a female speaker.

The comfort index for loud sounds 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. An example is shown left in Figure 7. The comfort index is a value in dB, and is an estimate of the amount by which a listener would reduce the volume 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.

Therefore, larger comfort index values would indicate that louder sounds are less comfortable.

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

$$\text{Adjusted index} = \text{audibility index} - \text{comfort index} / 30$$

The division by 30 is to convert the comfort index from a dB value with a 30 dB range to a dimensionless number with a range from 0 to 1 as in the calculation of the audibility index.

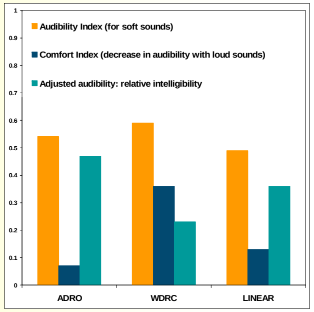


Figure 8. Component indices for the Adjusted Audibility Index

Discussion

As indicated by the measurements in the top two graphs in Figure 5, the audibility indices for the ADRO™ and WDRC hearing aids were similar. The audibility index for the linear hearing aid was slightly less than the other two. The comfort index predicted that the WDRC volume would be turned down most, followed by the volume of the linear aid. The comfort index predicted that the ADRO™ hearing aid would be the most comfortable of the three.

The adjusted audibility index, shown by the lighter blue bars in Figure 8, shows the ADRO™ aid produced the most advantageous balance of comfort and audibility out of the three hearing aids.

Results from clinical trials of wide dynamic range compression, linear amplification, and the new ADRO™ digital hearing aid were in accord with the predictions of the adjusted index, demonstrating its potential utility for fitting and evaluation[2,3]. The ADRO™ processing scored higher on speech intelligibility tests at low to medium 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 softer 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. The ADRO™ hearing aid performed at the high end of this range.

Conclusions

The adjusted audibility index is a useful tool for hearing aid comparisons. It correctly predicts that the ADRO™ processing scheme produces more comfortable listening levels than WDRC and linear hearing aids. As predicted, listeners using their preferred volume settings produce higher scores for speech perception at low input levels with ADRO™ than with the other amplification schemes.

References

1. Byrne D & Dillon H. The National Acoustics Laboratory (NAL) new procedure for selecting the gain and frequency response of a hearing aid, *Ear & Hearing 7* 257-265, 1986
2. Martin LFA, Blamey PJ, James CJ, Galvin KL & Macfarlane D. Adaptive dynamic range optimisation for hearing aids. *Acoustics Australia 29*, 21-24, 2001.
3. Martin L, Fiket H, Krauze K, Saunders E, & Blamey P. ADRO™ compared with 3-channel fast-acting compression. *Dynamic Hearing white paper*, 2002.

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