Designing Hearing Aid Technology to Support Benefits in Demanding Situations, Part 2

Published on Friday, 31 May 2013 14:53

By Lars Baekgaard, MSc, Steen Rose, and Hanne Pernille Andersen, PhD

Most hearing aid manufacturers have chosen to implement the dynamic range of the A/D converter in the vicinity of under 10 dB SPL to less than 100 dB SPL, in view of the fact that even the loudest speech components will usually be within 85-90 dB SPL. Even though all levels of speech may be covered by a 0-96 dB dynamic range, other more intense inputs—such as live music or speech produced in the presence of loud noise—may be distorted because they exceed the upper limit of the A/D converter.

In recent years, the main focus of the hearing aid industry has been on optimizing sound in normal, everyday situations. State-of-the-art wireless hearing aids typically offer a vast range of sophisticated features (eg, multichannel processing, adaptive directionality, feedback canceling, noise reduction, frequency shifting, multistage compression strategies, etc) that are very efficient in optimizing sound quality at normal input levels.

However, there are still opportunities for improvements in other, less frequent environments, such as those with loud sound levels. This paper reports a recent trial that tested the efficacy of a new wireless hearing aid in a situation characterized by loud inputs.

As discussed in Part 1 of this article in the March 2013 *HR*,[1] until now, even highly sophisticated wireless hearing aids have not been very adept at handling loud input levels. As a rule, sound levels exceeding 100 dB SPL are distorted because the analog-to-digital (A/D) converter in the hearing aid has an upper limit of about 100 dB SPL. If the input signal exceeds the A/D converter's input range (ie, its upper limit), the A/D converter is overloaded, resulting in highly perceptible distortion (clipping)—typically perceived as a "crackling" or "raspy" sound quality by hearing aid wearers. Once distortion is introduced into the signal, it is impossible to improve the sound quality at a later stage in the signal processing.

An input range of approximately 100 dB SPL is sufficient if speech perception at normal levels is the only concern, since the loudest speech components are usually within 85-90 dB SPL, even at a shout. However, other types of input are much more intense. For instance, music played at a medium to loud volume level may easily exceed 100 dB SPL.[2,3]

As an alternative to allowing clipping distortion, some hearing aid manufacturers employ a technique known as Automatic Gain Control, Input (AGCi) (also known as *input compression*). Basically, AGCi constantly compresses the input signal to make sure that it remains below the distortion limit of the A/D converter. However, a major drawback of this technique is that, while it eliminates clipping artifacts, it can also introduce dynamic artifacts. These include the smearing of intensity cues, "pumping," or a "dull" sound quality.[1]

While there is a solid body of literature describing the detrimental effect of peak clipping and automatic gain control (AGC) on speech perception and subjectively perceived sound quality,[4-8] the authors found no studies that directly compare the effect of artifacts introduced by peak clipping and AGCi at the A/D conversion stage. Even though it is difficult to decide which technique is superior based on the available literature, the fact remains that both techniques have been found in the literature to have a relatively strong detrimental effect on speech comprehension and perceived sound quality—suggesting that the best strategy is to avoid both, if at all possible.

This prompted Widex to search for new ways to ensure that louder signal levels could pass through the A/D converter without introducing distortion. The result is a new A/D converter with an upper limit of 113 dB SPL, and it is available in the Widex DREAM hearing aid family (see Baekgaard et al[1] for a detailed description of the A/D converter).

The increased headroom of the A/D converter can be expected to generate benefits for the hearing aid wearer in a number of different real-life situations with loud inputs, such as when the wearer is trying to hear speech at a busy restaurant or on a busy street with a lot of traffic noise. The efficacy of the Widex DREAM hearing aid in improving speech recognition in loud noise has recently been explored in a laboratory trial with hearing-impaired listeners. Details of the experimental setup and the results are described below.

Efficacy of Improving Speech Perception in Loud Noise

Subjects. A total of 10 subjects with mild to moderately severe sensorineural hearing loss participated in the study. Their ages ranged from 48 to 69 (mean age: 62 years).

Initial inclusion criteria were symmetrical mild to moderately severe sensorineural hearing loss, with PTAs no greater than 60 dB HL at 0.5, 1, 2, and 4 kHz, discrimination scores of 80 or greater in quiet, and 12 months of experience wearing hearing aids. However, such a group proved difficult to recruit. Two participants with PTAs of 65 dB HL at 4 kHz (# 1 and #6), and one participant with a discrimination score of 72 on one ear (#10) were therefore included in the trial. The results obtained for these 3 subjects were not observed to differ systematically in any way from the rest.

As the study sought to test speech perception in loud noise, potential subjects with sound intolerance related conditions (hyperacusis, phonophobia, etc) were excluded from the trial. The participants' audiograms (averaged across the left and right ears) and discrimination scores are shown in Figure 1 and Table 1.

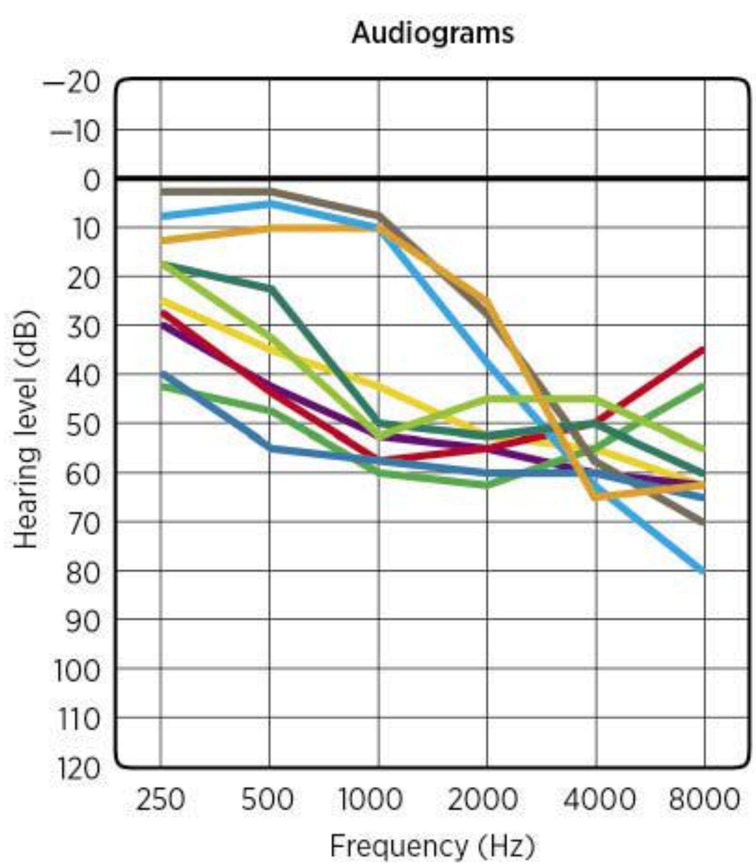

Figure 1. Audiograms of the 10 participants included in the trial (averaged across the left and right ears).

DISCRIMINATION SCORES (DS) IN QUIET		
Participant #	Left ear	Right ear
1	88	88
2	96	88
3	88	92
4	92	84
5	100	92
6	84	92
7	92	88
8	96	96
9	92	88
10	72	92

Table 1. Discrimination scores (DS) in quiet for the 10 participants included in the study.

Procedures. The hearing aids used in the trial were Widex DREAM440 FUSION hearing aids with P-receivers and a reference hearing aid of similar construction and power. Both are wireless high-end RITE devices. The operating range of the A/D converter in the reference hearing aid is approximately 7-103 dB SPL, whereas the A/D converter in the Widex DREAM has an operating range of approximately 17-113 dB SPL. A pair of each of the test hearing aids was fitted individually to each participant's hearing loss prior to the test.

The participants' speech-in-noise performance was investigated in a single-blinded study by means of a Danish word recognition test (Dantale). The Dantale test[9] comprises 8 lists of 25 commonly occurring monosyllabic Danish words (nouns, verbs, and adjectives). Words that can be emotional or objectionable, as well as words with phonetic elements known to cause confusion, have been excluded from the lists. The original test also includes an amplitude-modulated, speech-shaped noise signal designed to emulate multi-talker babble. However, it was decided to use the noise signal from the Matrix test[10,11] in the trial instead, as this noise signal is judged to be a particularly good match for the frequency response of the speech material. Speech and noise were presented at a fixed SNR of -6 dB (signal level at 98 dBC and noise level at 104 dBC measured at the KEMAR's ear), since pilot tests had indicated that the sensitivity of the test was greatest with the given noise signal at this particular SNR.

Speech stimuli were delivered from a loudspeaker located directly in front of a KEMAR wearing the test hearing aids, while the noise was delivered via 3 loudspeakers at 90^{0}, 180^{0}, and 270^{0}. The participants listened to the speech stimuli from an adjoining room through headphones connected to the test hearing aids. Listeners were permitted to adjust the presentation level by turning a knob on the amplifier during a practice trial prior to the real test. They were instructed to aim for a loud environment (eg, a party with loud music).

Pilot trials had revealed that listening to a mixture of speech and noise at an average input level of 104 dB SPL for a lengthy period of time to be a highly unpleasant experience for both normal-hearing and hearing impaired listeners. Consequently, a decision was made to allow the participants to listen to the test signal through headphones connected to the hearing aids on the KEMAR's head. This test setup was deemed desirable, since it permitted the participants to listen to the test hearing aids' input signal at the original SNR, but not at an uncomfortably loud average input level of 104 dB SPL. The test setup is illustrated in Figure 2.

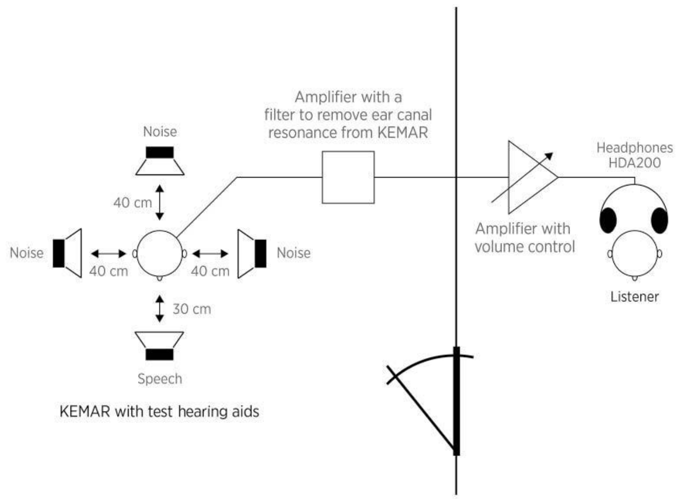

Figure 2. Illustration of the test setup. Speech was delivered from a loudspeaker located directly in front of a KEMAR wearing the test hearing aids, while the noise was delivered via three loudspeakers at 90°, 180°, and 270°. The participants listened to the speech stimuli from an adjoining room through headphones connected to the test hearing aids.

Scoring was done using the so-called "triple-score method," where the total word score is calculated on the basis of the correct identification of the initial consonant(s), the vowel, and the final consonant(s). Two lists comprising 25 words each were used in the trial. A practice list was run prior to the trial. The final result, shown in Figure 3, reflects the percentage of correct responses obtained for the latter 16 words in each list

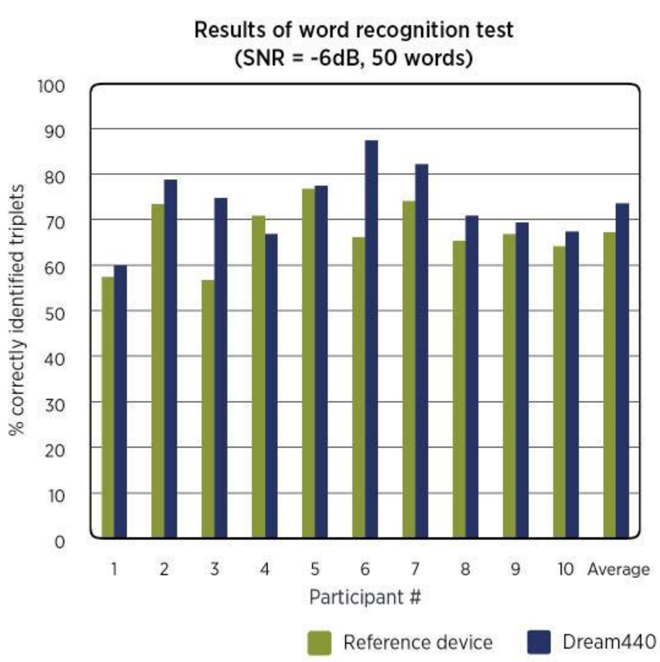

Figure 3. Results of the speech recognition test. The bars indicate the percentage of correctly identified triplets with the DREAM vs the reference hearing aids.

The default settings and features (eg, adaptive directional microphone system, noise reduction algorithm, feedback cancellation algorithm, etc) of the test hearing aids were enabled during the trial.

The test was conducted in two short sessions, between which the test hearing aids were changed on the KEMAR. Listeners were not permitted to adjust the volume subsequent to the practice trial.

Results

The results of the trial are shown in Figure 3. The bars indicate the percentage of correctly identified triplets with the DREAM versus the reference hearing aids. Although the individual performances of the participants varied, the vast majority (9 of the 10 participants) had better speech recognition in loud noise with the DREAM hearing aids than with the reference hearing aids. Improvements of as much as 18% to 21.3% were observed for some of the participants with the DREAM hearing aids, compared to with the reference hearing aids. On average, a statistically significant improvement of 6.3% was observed in the participants' speech recognition accuracy in noise with the DREAM hearing aids compared to with the reference hearing aids ($p<0.05$).

Thus, the results of the trial indicate that hearing-impaired listeners may achieve a higher speech identification performance in loud noise with the DREAM440 hearing aid than with a similar high-end hearing aid with a lower dynamic range.

Conclusion

For many years, the hearing aid industry has been concentrating its efforts on improving speech perception in different environments, while other inputs like music have been a secondary consideration. Historically, therefore, most hearing aid manufacturers have chosen to implement the dynamic range of the A/D converter in the vicinity of under 10 to less than 100 dB SPL. This range was implemented because, even if you shout, the loudest speech components are usually within 85-90 dB SPL. Although all levels of speech may be covered by a 0-96 dB dynamic range, other inputs—including more intense inputs such as live music or speech produced in the presence of loud noise—may be distorted because they exceed the upper limit of the A/D converter.

Widex has therefore introduced a new hearing aid family, DREAM, that offers a dynamic range of approximately 17-113 dB SPL, rather than the conventional range of under 10 to less than 100 dB SPL in the older generations of converters. The new A/D converter has been designed to handle all signal levels optimally, including very loud signal levels. Shifting the dynamic range in the A/D converter upwards to the 17-113 dB range means that more loud input is allowed to pass through undistorted, while the audibility of soft sounds is still preserved.

Hearing aid wearers are likely to derive benefit from the increased headroom of the DREAM A/D converter in a number of different situations characterized by high sound levels. The potential benefits of the new hearing aid were explored in one such situation where speech was presented in the presence of loud noise. The hearing-impaired listeners achieved a significantly better average speech recognition score with the DREAM440 hearing aids, whose A/D converter has an operating range of approximately 17-113 dB SPL, than with a similar pair of wireless high-end hearing aids with a "conventional" A/D converter operating range of approximately 7-103 dB SPL. A statistically significant average improvement of 6.3%, and individual improvements of as much as 18% to 21.3%, were observed in the study.

  

Lars Baekgaard, MSc, is Team Leader in the Widex R&D department; Steen Rose is a Clinical Trial Manager in the Widex Applied Research Team; and Hanne Pernille Andersen, PhD, is an Evidence Researcher in the Widex Evidence Team.

References

1. Baekgaard L, Knudsen NO, Arshad T, Andersen HP. Designing hearing aid technology to support benefits in demanding situations, Part 1. *Hearing Review*. 2013;20(3):42-59. Available at: http://www.hearingreview.com/products/21462-designing-hearing-aid-technology-to-support-benefits-in-demanding-situations-part-1

2. Chasin M. Hearing aids for musicians. *Hearing Review*. 2006;13(3):24-31. Available at: http://www.hearingreview.com/practice-management/16216-hearing-aids-for-musicians

3. Chasin M. Amplification fit for music lovers. *Hear Jour*. 2010;63(9):27-30.

4. Boothroyd A, Springer N, Smith L, Schulman J. Amplitude compression and profound hearing loss. *J Speech Hearing Res*. 1988;46:44-47.

5. Dawson P, Dillon H, Battaglia J. Output limiting compression for the severe-profoundly deaf. *Austral J Audiol*. 1991;13(1):1-12.

6. Crain TR, Van Tasell DJ. Effects of peak clipping on speech recognition threshold. *Ear Hear*. 1994;15(6): 443-453.

7. Kozma-Spytek L, Kates JM, Revoile SG. Quality ratings for frequency-shaped peak-clipped speech. *J Speech Hear* Res. 1996;39:1115-1123.

8. Arehart KH, Kates JM, Anderson MC, Harvey LO Jr. Effects of noise and distortion on speech quality judgements in normal-hearing and hearing-impaired listeners. *J Acoust Soc Am*. 2007;122(2):1150-1164.

9. Eberling C, Ludvigsen C, Lyregaard PE. DANTALE: A new Danish speech material. *Scand Audiol*. 1989;18:169-175.

10. Wagener K, Josvassen JL, Ardenkjaer R. Design, optimization and evaluation of a Danish sentence test in noise. *Int J Audiol*. 2003;42(1):10-17.

11. Wagener KC, Brand T, Kollmeier B. International cross-validation of sentence intelligibility tests. Proceedings of the 8th EFAS Congress/10th Congress of the German Society of Audiology, Heidelberg, Germany, June 6-7, 2007:1-3. Available at: www.uzh.ch/orl/dga2007/Program_EFAS_final.pdf