Noise reduction in modern hearing aids – long-term average gain measurements using speech

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The current study aims at showing how noise reduction algorithms of contemporary hearing aids function for real speech in noise. Twelve modern hearing aids were used. Coupler gain measurements were performed in an acoustic test chamber using a real speech signal in stationary speech-weighted noise. Recordings of the input to and output from the hearing aids, with the noise reduction switched on and off, were used to calculate long-term average gain reduction due to the noise reduction. The results, presented as contour plots, show large differences among the various noise reduction algorithms. The hearing aid manufacturers have obviously chosen to design their noise reduction algorithms based on completely different principles.

BACKGROUND

Modern hearing aids normally incorporate noise reduction (NR) algorithms. Most NR algorithms are modulation based, i.e., they use the well-known modulation pattern of speech to distinguish between speech and noise. They make this speech/non-speech distinction in a number of frequency channels where compression characteristics can be adjusted depending on the signal-to-noise ratio (SNR) in that particular frequency channel.

There are no standard measurements available that can describe how these NR algorithms work. Therefore, audiologists have a hard time choosing a hearing aid with the type of algorithm they think would be beneficial to a patient. When it comes to tenders for public health care, the specification is usually only if a NR system is available or not, not specifying what it actually does.

It is far from trivial to quantify the effect of noise reduction in hearing aids. Hoetink *et al*. (2009) compared long-term average gain measurements with speech-like signals with and without the noise reduction switched on. Leijon and Nordqvist (Leijon and Nordqvist, 1999; Nordqvist and Leijon, 2002) showed what different NR algorithms do for individual speech sounds, i.e., in the short time frame.

The main aim of the current study was to investigate ways to illustrate how noise reduction algorithms work. A second aim was to explore potential differences among modern hearing aids.

Measurements similar to those made by Hoetink *et al*. (2009) will be reported. The measurements differ from those of Hoetink *et al*. (2009) mainly in that real speech was used (rather than simulated speech), that the speech levels (rather than the overall levels) were kept constant when the SNRs were varied, and that comparisons were

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made between measurements with the NR on and off (rather than using the gain for clean speech as a reference). Short-term average gain measurements have also been used to quantify the effect of noise reduction in hearing aids, but the results of these measurements are only outlined in this presentation.

METHOD

Twelve modern hearing aids were programmed for three audiograms. Except for the NR algorithms, advanced signal processing in the hearing aids was turned off. Coupler gain measurements were performed in an acoustic test chamber, and measurements with the NR on and off were compared using contour plots.

Audiograms

Three audiogram configurations were used (Fig. 1) when programming the hearing aids, one flat loss at 50 dB HL, one gently sloping audiogram, KS100, and one of the suggested standard audiograms from the EHIMA draft, N4 (2007).

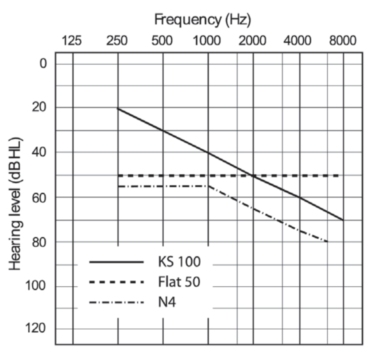

Fig. 1: The three audiogram configurations used in the study.

Hearing aids

In March 2008, twelve modern hearing aids were purchased for the project. The Swedish retailers of the hearing aids were informed about the project and selected the hearing aid they wanted to include in the study. These hearing aids were always among the high-end products from each company.

Hearing aid programming

The hearing aids were programmed using their dedicated fitting software under InfoTrack 1.1 (a Widex A/S database system built on the NOAH 3 platform). The default gain prescription for each hearing aid was used. Microphones were set in omnidirectional mode, maximum power output was set to its maximum value, and expansion, feedback reduction, volume controls, automatic program switching, and other types of signal processing were turned off. The NR settings were chosen to fit a situation with speech in speech-shaped noise. The programming was done in close cooperation with the Swedish hearing aid retailers from where the hearing aids were bought.

Equipment and material

The measurements were performed in a test box (TBS25, Interacoustics) using a PC with dedicated hearing instrument testing hardware (Equinox, Interacoustics) and software (HIT440, v. 1.11, Interacoustics). An IEC-60711 coupler (GRAS), reference and measurement microphones (40 AG, GRAS), preamplifiers (26 AC, GRAS) and amplifiers (12AK, GRAS) were used. The HIT440 automatically loads and calibrates the level of wideband signals, and compensates for the level and frequency characteristics of the test box by equalizing the response and calibrating the level before each measurement.

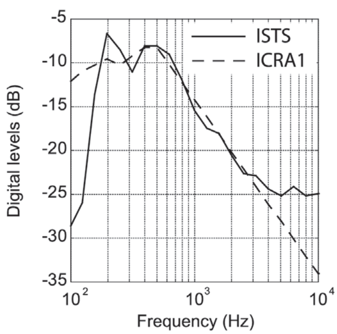

Fig. 2: Spectra for the speech signal (ISTS) and the speech-weighted noise (ICRA1).

The ISTS speech signal (EHIMA, Vlaming *et al*., 2007) was mixed with un-modulated speech-weighted noise, ICRA 1 (Dreschler *et al*., 2001), in seven SNRs, +6 to -12 dB in 3-dB increments, plus one situation with pure speech. The speech was kept constant at two presentation levels, 62 and 75 dB SPL, i.e., the overall presentation level varied with varying SNRs. The spectra for the speech and the noise are shown in Fig. 2.

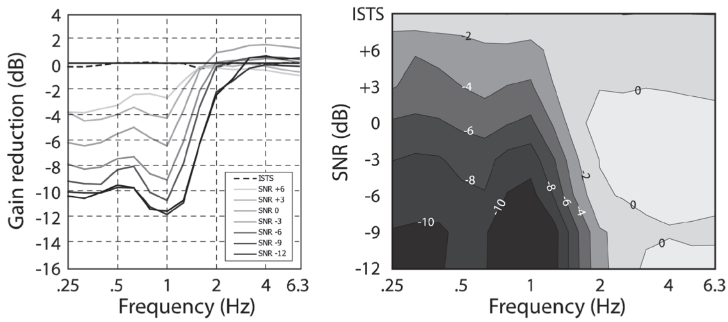

Fig.3: The left panel shows an example of the calculated gain reduction (measured gain with NR on minus measured gain with NR off) for the SNRs used. These gain reductions were re-plotted as reduction contours (right panel). The darker an area is, the larger the gain reduction. The small numbers on the contours indicate how large the gain reduction is in dB. The large gain reduction around 1 kHz seen in the left panel for this particular hearing aid, appears as the dark area (contour marked with 10) in the right panel. The fact that this particular hearing aid gives some gain in the high-frequency region for SNRs around 0 dB (left panel) is seen in the right panel as the lightly colored area (contour marked with 0) between 2 and 6 kHz for SNRs from approximately -8 to +2 dB.

Procedures

After a 30-second preconditioning time, when the mixed speech and noise signal was played and the hearing aid had time to adjust the NR, gain was measured during 30 seconds. For each measurement condition (combination of audiogram, presentation level, and SNR), gain measurements were performed with the NR on and off. The resulting gain curves were averaged (by averaging dB-values) within 1/3-octave bands from 250 to 6300 Hz. Gain reduction due to the NR (Fig. 3, left panel) was re-plotted as reduction contours as a function of frequency and SNR (Fig. 3, right panel). In these reduction contour plots, darker coloring indicates larger gain reduction.

RESULTS

First, a summary of the measurement results for all the hearing aids will be presented for one of the audiograms, the gently sloping KS100, and one presentation level, speech at 75 dB SPL (Fig. 4). It can be seen that for this particular measurement condition there is a large difference in how the hearing aid manufacturers have chosen to implement their NR algorithms. The algorithms differ in the amount of gain reduction that is applied and in the pattern of reduction across frequency. For some hearing aids (e.g., hearing aids G and E) the gain reduction is fairly limited, rarely exceeding 4 dB, whereas for some other hearing aids (e.g., hearing aids B, C, and I) the gain reduction is more substantial, exceeding 10 dB at certain frequencies. Large differences between the results for the various hearing aids were seen also for the other measurement conditions.

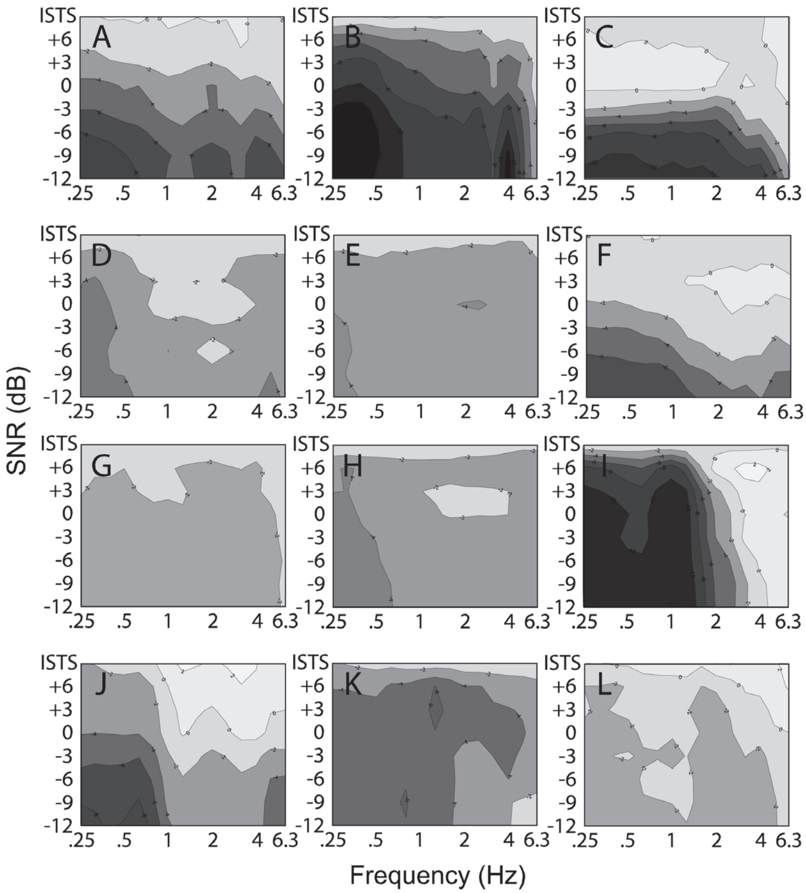

Fig. 4: Gain reduction contours for the 12 hearing aids (A-L) for the measurement situation with speech at 75 dB SPL and the KS100 audiogram.

In order to show what the various NR algorithms do for the three audiograms and the two presentation levels, three hearing aid examples will be given. In Fig. 5, the results for hearing aid G are presented. This hearing aid showed a small gain reduction (not exceeding 4 dB) and small differences between measurement conditions (selected audiogram and presentation level). In Fig. 6, the results for hearing aid I are presented. This hearing aid, on the other hand, showed a large gain reduction (up to 12 dB in the low-frequency range) and large differences between the six measurement conditions, with larger gain reduction for the higher speech level and the milder hearing loss. In Fig. 7, the results for hearing aid C are presented. This hearing aid showed a large gain reduction (exceeding 10 dB), but small differences between measurement conditions.

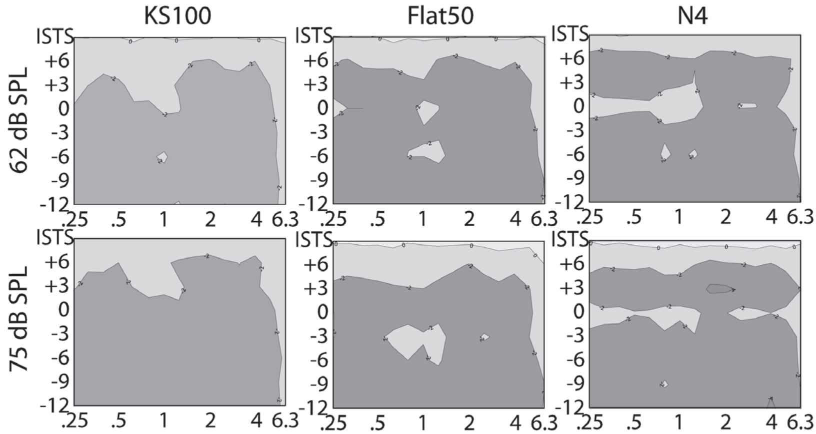

Fig. 5: Measurement results for hearing aid G. In the rows the two speech levels are represented, and in the columns the three audiograms are represented.

DISCUSSION

Measurements of long-term average gain reduction have been presented, and have shown that the included hearing aid NR algorithms are very different. Hoetink *et al.* (2009) also found large differences between hearing aids. It is somewhat difficult to directly compare the results of the two studies since most of the hearing aids used were different, but for one hearing aid, that was used in both studies, the results seem comparable despite the difference in measurement procedure between the two studies described in the introduction.

One thing that differed between the two studies was the "reference" the measurements were compared against. In the study of Hoetink *et al*. (2009), comparisons were made between gain measurements for the noisy signals and the gain measurements for the clean speech signal, whereas the current study compared gain measurements with the NR on and off. Since the current measurements were performed with a fixed speech level, the overall sound pressure level varied when the SNR was varied, which prevented a comparison with the clean speech signal as a reference since the measurements would be at different points along the static input-output function.

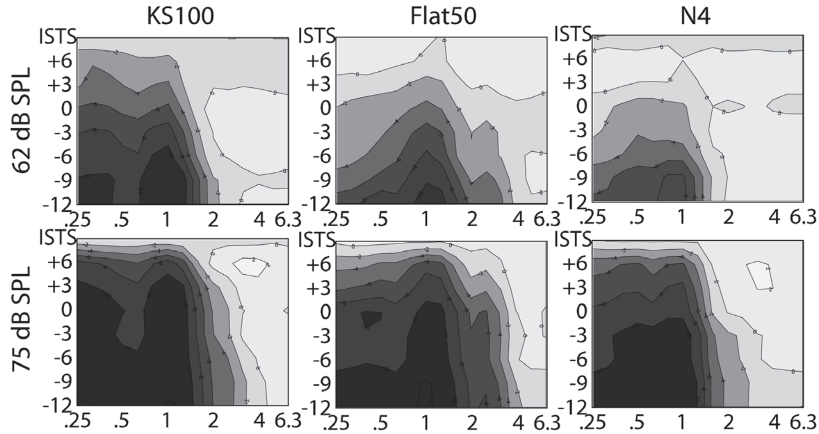

Fig. 6: Measurement results for hearing aid I. The layout is the same as in Fig. 5.

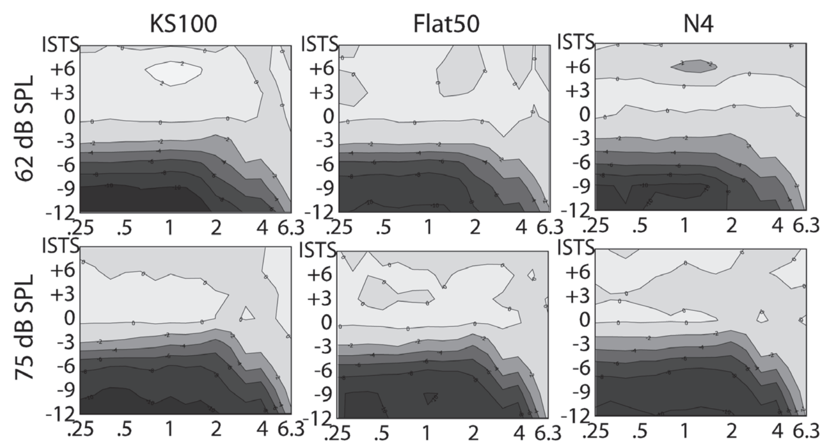

Fig. 7: Measurement results for hearing aid C. The layout is the same as in Fig. 5.

Additional measurements, using two fixed overall levels, revealed that for four hearing aids there was some NR on even when the feature was disabled in the software. This was manifested in higher gain for the pure speech signal than for measurement conditions where speech was mixed with noise.

All hearing aids were programmed with their default prescription. It is reasonable to question how the gain reduction due to the NR algorithm is related to the amount of prescribed gain, which acted as a baseline. Measurements at our laboratory have shown that there are large differences in prescribed gain among the various hearing aids, but there was no clear correlation between the amount of gain and the amount of gain reduction due to the NR algorithm.

These long-term average gain measurements have shown large differences among NR algorithms implemented in modern hearing aids. What happens in the short-term perspective? Short-term average gain measurements have been performed in our laboratory. The results have been presented in movies where the gain reduction due to the NR is illustrated together with the sound file the hearing aid has processed. This has proved to be an illustrative way to present the data. NR time constants can be studied, and the co-variation between gain reduction in different frequency ranges is easy to see. The results of these measurements have shown that NR algorithms that seemed to work in a similar way in the long-term perspective, could function very differently in the short-term perspective.

CONCLUSIONS

We have illustrated what noise reduction systems in modern hearing aids do in terms of long-term average gain reduction. The results have been presented in gain reduction contour plots, and show that there are large differences between the various systems. These variations include:

- the amount of gain reduction,
- the frequency range in which the main reduction is applied,
- the dependence on SNR,
- the dependence on audiogram configuration, and
- the dependence on speech level.

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