

An investigation of effective SNR-change through amplitude-compression hearing aids

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The long-term Signal-to-Noise Ratio (SNR) at the input and output of compression amplification hearing aids (HA) are measured and computed. Systematic changes of long-term SNR from input to output are found. These changes are affected by both compression system parameters and signal properties of speech and noise. Such SNR changes may potentially affect perceptual performance for users of compression HAs. This is also investigated, although the current standing of this work does not provide a clear conclusion.

EXAMPLE OF LONG-TERM SNR AT THE INPUT AND OUTPUT OF A HEARING-AID COMPRESSION SYSTEM

The long-term SNR at the output (Output SNR, SNR_{out}) of a HA with amplitude compression may differ from the long-term SNR at the input (Input SNR, SNR_{in}). Figures 1 to 3 exemplify how this SNR change can arise.

Figure 1 shows a mixture of speech and unmodulated noise at the input. The two signals have equal long-term frequency spectra and the Input SNR is SNR_{in} = +10 dB. Figure 2 shows the output from a simplified HA with fast-acting compression. Speech and noise are separated using the Hagerman & Olofsson (2004) technique. The gain of the HA varies over time due to compression and the fluctuating overall level of the input signal. This can potentially lead to different amplification of the speech and noise components. For example at positive Input SNRs, the stronger portions (speech) will receive less gain than the weaker portions (noise). For the input conditions shown in Fig 1 the result is SNR_{out} = +7 dB.

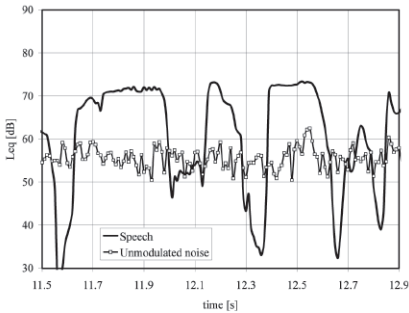


Fig. 1: Stimulus. SNR_{in} = +10dB.

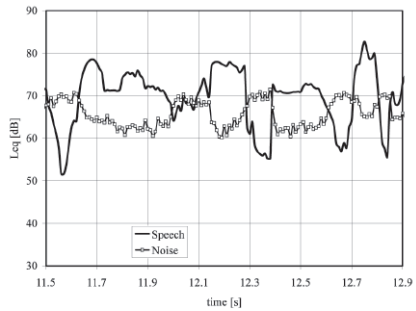


Fig. 2: Output from HA. SNR_{out} = +7dB.

Figure 3 shows SNR_{out} for a range of SNR_{in} from -14dB to +14dB. This is the same method as used by Souza *et al.* (2006). Each data point is based on one measurement and the example shown in Fig. 1 and 2 makes up the data point (+10dB, +7dB). Worth

noticing is that the SNR change depends on the Input SNR value. At large negative SNR_{in}, SNR_{out} is equal to SNR_{in}, due to the dominating non-fluctuating noise and hence constant gain.

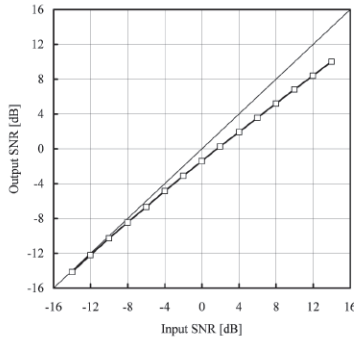


Fig. 3: Resulting SNR_{in} vs. SNR_{out} curve. Figure 1 and 2 make up the data point (+10dB, +7dB).

SYSTEMATIC HEARING-AID MEASUREMENTS OF LONG-TERM SNR CHANGE

A simple HA is used to measure the magnitude of the SNR change, when different types of signal mixtures are used. The HA used in these measurements is configured with fast-acting single-channel compression (attack time = 5ms, release time = 26 ms) and a compression ratio of 2:1 across all input levels. The stimuli are a mixture of Dantale II concatenated sentences simulating running speech and one of three different noise types. The three different noise types are: unmodulated noise, ICRA two-talker modulated noise, and speech-modulated noise. All four signals have equal long-term spectra as the Dantale II material.

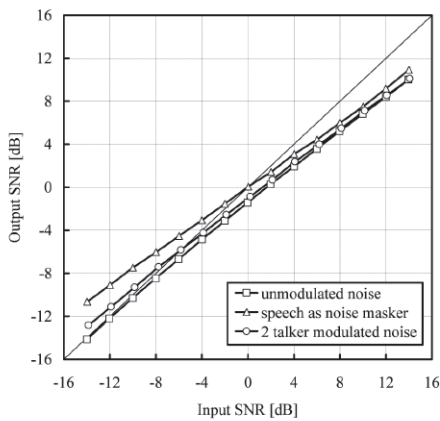


Fig. 4: SNR_{in} vs. SNR_{out} for different stimuli types.

Figure 4 shows that the magnitude of the long-term SNR change depends on the noise

type, and that the Output SNR deviates by up to ± 4 dB from the Input SNR. When the noise signal has significant modulation, the Output SNR may be both higher than and lower than the Input SNR, dependent on the Input SNR. The results using speech for both Noise and Signal (triangles) show that it is the weakest component that is relatively most amplified, i.e. at negative SNR_{in} the long-term SNR is 'improved' by compression. On the other hand, at positive SNR_{in} the long-term SNR is 'degraded' by compression.

The effect of compression parameters has also been investigated. More 'aggressive' compression (shorter time constants, higher compression ratios, more channels) always produces greater differences between Input SNR and Output SNR, but the crossover point between negative and positive difference is not affected (being dependent only on the relative modulation in the Signal and Noise).

PERCEPTUAL EFFECTS

It is natural to pose the question: Do long-term SNR changes of the sort observed above influence speech intelligibility? Previous work could indicate such effects (Olsen *et al.*, 2005). Here we present some preliminary data to illuminate this question.

Perceptual experiment design

The test method used is a speech recognition test scoring %-correct words using Dantale II speech material. 14 datasets with hearing-impaired test persons (8 of the datasets were produced by 4 test persons) and 2 datasets with normal-hearing test persons are collected. The stimuli used are a mixture of speech and either unmodulated noise or speech-modulated noise, as described above in the sections on HA measurements. Each dataset consists of three points, obtained with three different HA conditions. In one condition, a compression HA was used. In this condition, the Input SNR and Output SNR differ. The two remaining conditions used linear HAs (for which $\text{SNR}_{\text{in}} = \text{SNR}_{\text{out}}$). In one linear condition the Signal + Noise mixture was set with an SNR equal to the compression HA's Input SNR; in the other it was set with an SNR equal to the compression HA's Output SNR. Figure 5 shows a schematic and notation conventions for this design.

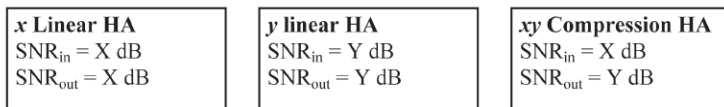


Fig. 5: The three conditions for the perceptual experiment.

This design allows us to test three possible assumptions:

- I. Long-term Output SNR (SNR_{out}) is an ideal estimator for speech intelligibility
- II. Long-term Input SNR (SNR_{in}) is an ideal estimator for speech intelligibility
- III. Neither I nor II is true, but there is a monotonic relation between speech intelligibility and both long-term SNR measures.

Results and discussion

The result of the perceptual experiment is sixteen datasets each containing three different %-correct measures. Five of these datasets are shown in Fig. 6. Trios of connected points represent datasets from individual subjects with a specific noise type. The labels x , y and xy refer to the measurements made with each of the three HA conditions shown in Fig. 5.

Data supporting each of the three possible assumptions will have a distinct appearance in the display format of Fig. 6.

- I. If assumption I is true; then the compression HA xy has equal speech intelligibility to the linear HA y , indicated by close vertical spacing between y and xy .
- II. If assumption II is true; then the compression HA xy has equal speech intelligibility to the linear HA x , indicated by close vertical spacing between xy and x .
- III. If assumption III is true; then the angle x - xy - y will be oblique.

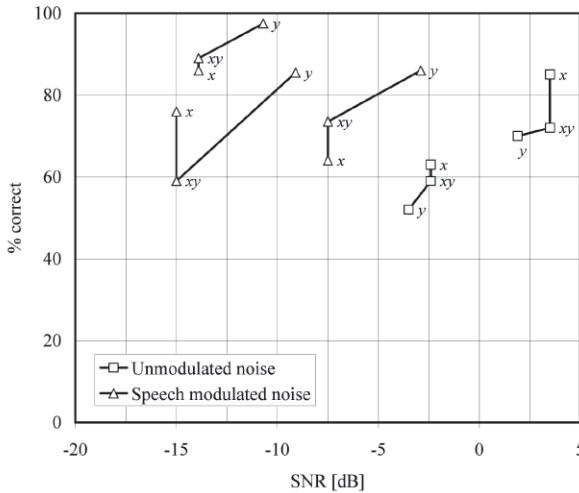


Fig. 6: Examples of datasets.

In Fig. 6 the right-most dataset (squares) supports assumption I, as the compression HA xy results in almost the same %-correct as the linear HA y with the same SNR_{out} . The uppermost set (triangles) and bottom set (squares) are two examples supporting assumption II, whereas the middle set supports assumption III. The left-most dataset (triangles) is an example that does not support any of the three assumptions.

Apart from this one 'renegade' dataset, Fig. 6 also shows that the measurements in unmodulated noise with a compression HA result in worse performance than with a linear HA at the same SNR_{in} , whereas with speech-modulated noise a compression HA provides better performance than the linear HA at the same SNR_{in} , just as would be predicted from Fig. 4 for the Input SNRs in question. In Fig. 7 it can be seen that this holds for all but two of the sixteen measurements.

Figure 7 shows all 16 datasets as differences in %-correct from the linear HA x . Each dataset is thus represented by two columns. The table to the right of Fig. 7 indicates which measurements support which assumptions. Note that some of the measurements show ambiguous results, and can therefore be said to support more than one assumption.

- I. The assumption that SNR_{out} is the better estimator of speech intelligibility is supported if the two columns are roughly equally high.
Occurrence: 4 of 16 measurements
- II. The assumption that SNR_{in} is the better estimator of speech intelligibility is supported if the left column has zero height (or close to it)
Occurrence: 7 of 16 measurements
- III. Assumption III is supported if the height of the right column is greater than the height of the left column, but has the same sign.
Occurrence: 9 of 16 measurements
- (IV.) One measurement (no. 9), potentially an outlier, does not support any of the three assumptions, and one measurement (no. 2) shows virtually no difference between all three scores, the probable explanation being small effective SNR differences.

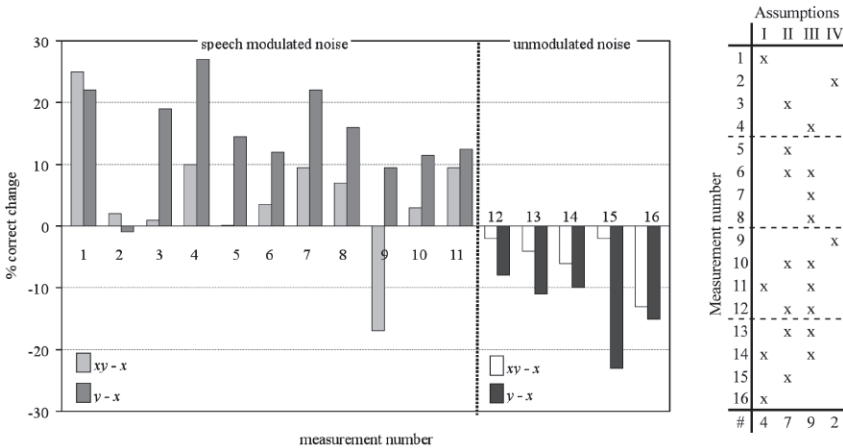


Fig. 7: All 16 datasets. y and xy shown as %-correct difference from x . The table to the right indicates which measurements support which assumptions.

For all measurements with speech modulated noise, it holds that condition y has a higher SNR than condition x . It is therefore expected that the %-correct difference $y - x$ should be a positive number showing a positive linear relation between SNR_{in} and speech intelligibility. For the measurements with unmodulated noise the opposite holds, namely that y has a lower SNR than x .

Figure 7 shows a trend such that the *direction of change* in long-term SNR from input to output appears to be a good predictor for the *direction of change* in speech intelligibility for 12 out of 16 test subjects (datasets 2, 3, 5 and 9 does not support this). It is also seen that the change in intelligibility due to an SNR change at the input to a linear system tends to be greater than the effect of the same SNR change from input to output of a compression system. This holds for both the tested noise types, and/or both upwards and downwards.

CONCLUSION

- Amplification through a compression system can change the long-term SNR by several dB from input to output. Both compression parameters and signal properties influence these changes.
- The direction of change in long-term SNR from input to output of a compression hearing aid seems to be a good predictor for the direction of speech intelligibility change relative to a linear hearing aid with the same Input SNR.
- Neither the long-term input SNR, long-term output SNR nor a linear combination of both, explain the full perceptual effect of compression amplification on a speech and noise mixture.
- More work is required regarding generalisation of these preliminary results.

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