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Hearing-Aid Compression: Effects of Channel Bandwidth on Perceived Sound Quality

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Several researchers have investigated the effect of hearing-aid compression (the compression speed and the compression ratio) on speech perception and the sound quality of hearing aids. Some of these experiments have revealed positive effects of fast compression. However, the majority of the experiments have been conducted on simple hearing-aid platforms with only one to four compression channels. Today, high-end hearing aids have significantly more frequency channels. The question is therefore whether the results found with wide channel bandwidths can be extended to narrower channel bandwidths.

To investigate this, 10 normal-hearing subjects were asked to rate perceived sound quality of 111 pre-processed sound recordings differing on the four parameters of compression ratio, compression speed, signal to noise ratio and channel bandwidth. The results of the study showed that increased channel bandwidth is a very important parameter in relation to improving sound quality when compression ratio and compression speed are increased. Therefore, extending positive results of fast compression with wide frequency-channel bandwidths to hearing aids with narrower frequency-channel bandwidths should be done with caution.

INTRODUCTION

Several researchers have investigated the effect of hearing-aid compression (compression speed and compression ratio) on speech perception and the subjectively perceived sound quality of hearing aids (e.g. Gatehouse *et al*., 2006; Hansen, 2002; Neuman *et al*., 1998). Even though the results have been inconsistent, the general picture seems to be that slow compression is preferred on subjective sound quality scales. In 2006 Gatehouse *et al*. evaluated the benefits of fast and slow-acting compression, for listening comfort and speech intelligibility. Their study concurred with the general picture, showing that slow-acting compression outperforms fast-acting compression for listening comfort, while the converse is true for speech intelligibility. Besides their own study, the article also includes a literature review of the results of fast and slow acting compression. Examining this review more closely reveals that the majority of experiments done within this area – including their own - use platforms with only one to four compression channels. This is incommensurable with today's high-end hearing aids where significantly more channels are used and it might therefore be problematic to extend the results to

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high-end hearing aid compression of today. Experience suggests that results found within this area could be highly dependent on the number of compression channels. Fast compression has commonly been argued to increase audibility of weak parts of the signal, potentially leading to better audibility and speech intelligibility. However, fast compression in wide compression channels work a lot different than compression in narrow channels. Fast compression in narrow channels leads to less contrast between peaks and valleys in the frequency spectrum and thereby more smearing in the temporal and spectral domain. Slow compression, on the other hand, works in the same way in both wide and narrow channels and has the benefit of not distorting the signal in the temporal domain. The signal is only adjusted slowly in the spectral domain. However this has the disadvantage that weak parts of the signal following powerful parts may become inappropriately low or even inaudible.

Only two studies in the literature review of Gatehouse *et al*. use platforms commensurable with high end hearing aids of today, namely Hansen (2002) and Moore *et al*. (2004). Hansen (2002) investigated the effect of varying attack release time, in a 15 channel simulated hearing aid using a fixed compression ratio of 2, on subjectively rated speech intelligibility and sound quality. He found significant preference for slow acting compression. Moore *et al*. (2004) used a 20 channel compressor set up, and a test for the identification of nonsense syllables in quiet and in three types of background noise. They conclude that speech intelligibility is not markedly affected by the change of time constants. Even though both of these studies take more channels into account, none of the studies investigate the effect of varying the number of channels or the bandwidth of the filter in the processing.

A question that might be asked is therefore whether the results found with wide channel bandwidths can be extended to narrower channel bandwidths, or if narrowing the bandwidth filters constitutes a completely different setup?

AIM OF THE STUDY

The aim of this study was to investigate the influence of channel bandwidths, in combination with other relevant parameters, including compression time constants, compression ratio and signal to noise ratio on subjectively evaluated sound quality parameters.

METHOD

10 normal-hearing subjects were asked to rate the perceived sound quality of 111 pre-processed sound recordings differing on the four parameters of compression ratio, compression speed, signal-to-noise ratio, and channel bandwidth.

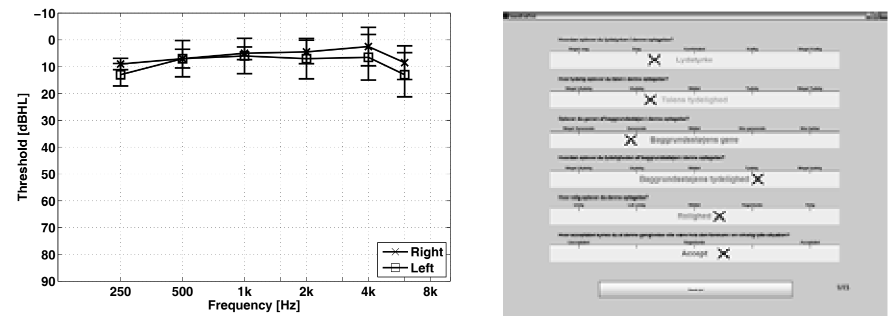

Fig. 1: Left: Mean and variance of the 10 normal hearing subjects hearing thresholds. Right: Picture of the input screen showing the 6 categorical scales.

The sound quality scale used was a categorical scaling setup, inspired by Neuman *et al.* (1998) and Schmidt (2006), with six sound quality related features (loudness, speech clarity, annoyance from background noise, clarity of background noise, calmness, and overall acceptance). The categories on the individual scales were:

- Loudness: very soft, soft, comfortable, loud, very loud.
- Speech clarity: very unclear, unclear, average, clear, very clear.
- Annoyance from background noise: very annoying, annoying, average, not annoying, not audible.
- Clarity of background noise: very unclear, unclear, average, clear, very clear.
- Calmness: very uneasy, uneasy, average, calm, very calm and
- Overall acceptance: unacceptable, tolerable, acceptable.

The stimuli used were:

1. Normal speech level, male speaker in dinner party noise (+ 25 dB SNR)
2. Normal speech level, male speaker in dinner party noise (+ 15 dB SNR)
3. Loud speech level, male speaker in dinner party noise (+ 5 dB SNR)

All were presented at 62 dB SPL. Each signal had duration of 27 seconds.

The compression ratios were 1, 1.5, 2, and 3, respectively. The attack/release speeds were 10/105ms, 42/420ms, 168/1680ms, 700/7000ms (IEC 60118-2 1983), and the frequency bandwidths of the filters in the gain calculation path were approximately 1/3 Octave (~15 band processing), 3/3 Octave (~5 band processing), and 5/3 Octave (~3 band processing), respectively.

The stimuli were equalized to the same 1/3 oct RMS spectrum as the input signals and presented to the listeners with the NAL-RP linear rationale in accordance with their measured thresholds.

RESULTS/DISCUSSION

To present a general mean score for all the processing strategies/combinations, the results for all 3 signal to noise ratios have been combined and plotted in bar plots of Fig.2. Scores are plotted as numbers between 0 and 1 mapping the input scale linearly, with the lowest category score being 0.1 - unacceptable and the highest score being 0.9 - acceptable.

The results show that all processed sounds were within a comfortable range on the loudness scale. This is as expected since all files were processed and equalized to the same spectrum (62 dB SPL overall) and amplified according to the measured thresholds using NAL-RP. The loudness with fast and high compression ratios was slightly elevated, however (see Fig. 2). This is a likely effect of the “pulling up” of the noise and the sound becoming more continually loud as opposed to the slow compression/low compression ratio strategies having a more modulated signal structure.

When the speed was faster than 700/7000ms, scores on subjectively evaluated sound quality parameters decreased as a function of increased speed, increased compression ratio and narrower bandwidth.

At slow compression speeds (full lines in Fig. 3), acceptance was independent of channel bandwidth and compression ratio. The overall acceptance did however, decrease with decreasing SNR, but to no greater extent that was seen with linear processing.

Increased compression speeds (dashed and dotted lines) had a negative impact on acceptance. Generally, acceptance became increasingly lower with increased compression speeds, higher compression ratios, and narrower bandwidths.

Lastly, the results revealed that the effect of changing the compression parameters seemed to decrease with decreasing SNR. However, this could be because of the floor effects when doing categorical scaling or the compression affecting the signal less and less due to smaller dynamic range in the input signal.

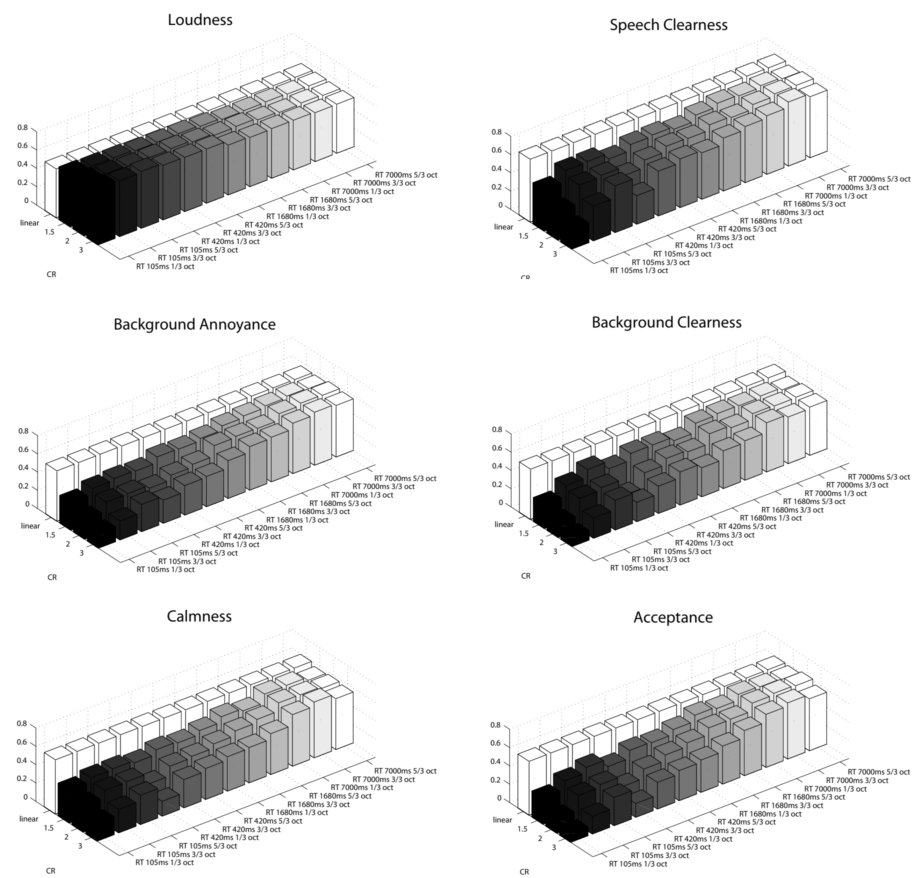

Fig. 2: Mean scores (0 to 1) across all input sounds as a function of compression ratio, and attack/release speed and bandwidth.

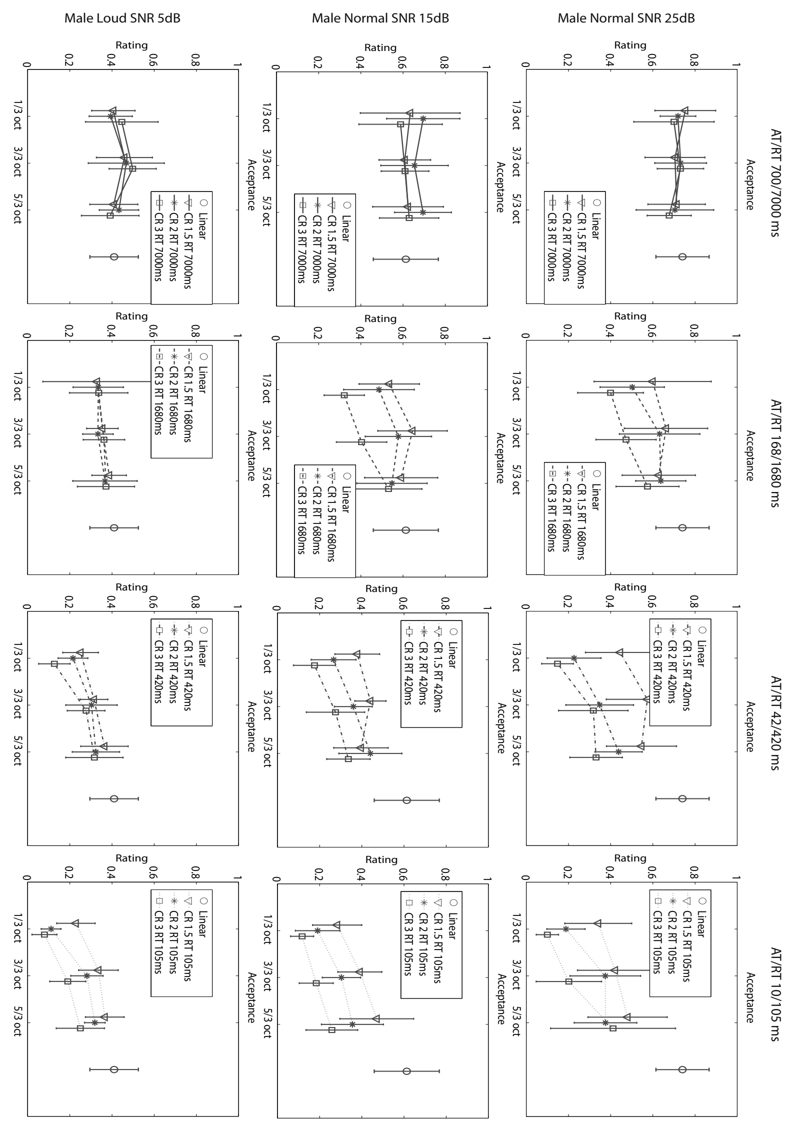

Fig. 3: Acceptance scores (0 to 1) across all input sounds at 25 dB SNR (rightmost column), 15 dB SNR (middle column), and 5 dB SNR (leftmost column). Attack/release speeds increased from 700/7000ms (top panel) to 168/1680ms, 42/420ms, and 10/105ms (bottom panel). Individual plots show acceptance ratings as a function of bandwidth for the different compression ratios. All results are plotted as mean and one standard deviation of the responses of the 10 subjects.

CONCLUSION

The results of the present study suggest that channel bandwidth may be a very important parameter in relation to sound quality. The results indicate that at high compression speed, acceptance generally decreases as channel bandwidths become narrower.

The results of this study imply that in order to achieve acceptable sound quality at favourable signal-to-noise ratios, fast compression should only be applied with very low compression ratios in hearing aids with narrow frequency channels bandwidths.

It should be noted that the study was conducted with normal hearing subjects who represent the mildly-impaired section of the hearing impaired population. Using subjects with higher audiometric thresholds may be expected to have an effect on the audibility of soft sounds. Hansen (2002) showed some differences in scoring between hearing-impaired and normal-hearing subjects, possibly related to the audibility of soft sounds, but slow compression was still preferred.

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