Replication of experiments on the ability to benefit from temporal fine-structure information in speech among persons with moderate cochlear hearing loss

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Introduction

- Several recent studies (Lorenzi et al, 2006; Hopkins & Moore, 2007; Hopkins et al, 2008) have shown that hearing-impaired subjects may be less able to extract information from temporal fine structure (TFS) than normal-hearing subjects. This may partially explain why subjects with cochlear hearing loss generally benefit less from fluctuations in background noise (than normal-hearing listeners).
- These findings are of great interest to the hearing aid industry since they suggest an unexplored phenomenon with regard to hearing impairment and hearing aids. However, it is important that the results can be replicated with new languages, new speech material, new background talkers, and for different pools of hearing-impaired subjects.
- Here, we wanted to replicate some of the previous findings on hearing-impaired subjects:
  - → **Experiment 1 was aimed at replicating the tone vocoder (N=32) results of Hopkins et al (2008)**
  - → **Experiment 2 was aimed at replicating the inability to discriminate complex tones with different TFS according to Hopkins et al (2007) with a newly developed TFS test (Moore & Sek, 2008).**
- Note that this is work in progress; the full data set has not been collected yet.

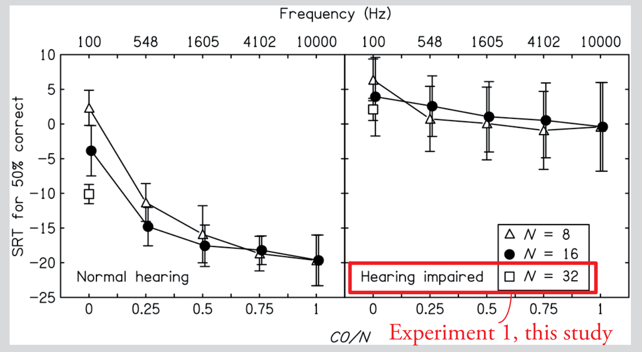


Fig 1. Results from the tone-vocoder Experiment in Hopkins et al (2008). Mean SRTs for normal-hearing and hearing-impaired subjects, plotted as a function of CO/N

Experiment 1

- Speech reception thresholds (SRTs) were measured using an adaptive procedure with Dantale 2 sentences (Wagener et al, 2003) and competing talker background.
- Amplification was applied to the combined signal as prescribed by the CAMEQ hearing aid fitting* method (Moore et al, 1998). All individual prescriptions led to a speech intelligibility index (ANSI S3.5, 1997) above 0.55, which was considered acceptable.
- Subjects were trained for 1+ hr using similar tone-vocoded stimuli as in the test, before data were collected.
- A working memory test (Reading Span [RS] see Lunner, 2003) to assess cognitive abilities was included in the test.

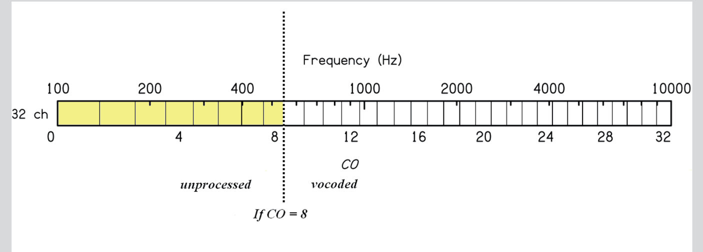
* for some of the subjects an 'alternative' amplification with more low-frequency and less high-frequency amplification was prescribed by mistake, but no statistically significant difference in performance was observed and therefore they were treated as equal to the CAMEQ prescription in this study

Stimuli

- Stimuli had variable amounts of TFS information. Stimuli were filtered into N = 32 channels and low-frequency channels up to a cutoff channel (CO) were left unprocessed. Higher-frequency channels were tone vocoded so that they contained no TFS information.

Processing

Fig 2. Example: For CO = 8, information in the shaded channels was left unprocessed, and information in the unshaded channels was vocoded



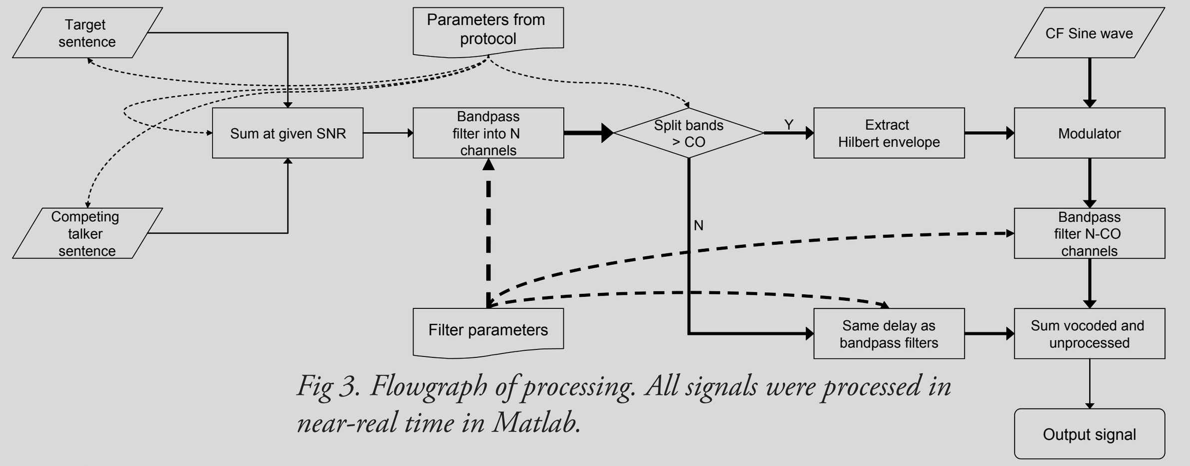


Fig 3. Flowgraph of processing. All signals were processed in near-real time in Matlab.

Subjects

- Eighteen hearing-impaired subjects, aged from 30 to 82 years, with mean age of 61 years, had air/bone gaps of 15 dB or less, and normal tympanograms. The hearing-impaired subjects showed no dead regions, as assessed using the 'TEN HL' test (Moore et al., 2004). Experiment 2 used a subset of nine hearing-impaired subjects.

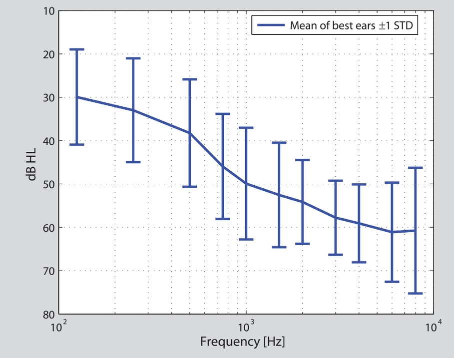


Fig 4. Mean air conduction audiometric thresholds and ± one SD of the test ears of the hearing-impaired subjects.

Results

- A repeated measures analysis of variance (ANOVA) was performed using the SRTs with a within-subject factor of CO.
- **The effect of the CO factor was highly significant (p < 0.001).**
- Post hoc Fisher's LSD tests were used to compare different levels of CO.
- **SRTs for conditions with CO > 12 were not significantly different from each other. This replicates the findings for the hearing-impaired subjects tested by Hopkins et al (2008).**
- **Performance improved with CO for some subjects (mainly below 1.5 kHz), presumably because they could benefit to some extent from the additional TFS information.**
- Subjects with high scores on the working memory test (RS above 30) showed better absolute SRT performance, in particular for CO=32. This is consistent with the findings of Lunner (2003).

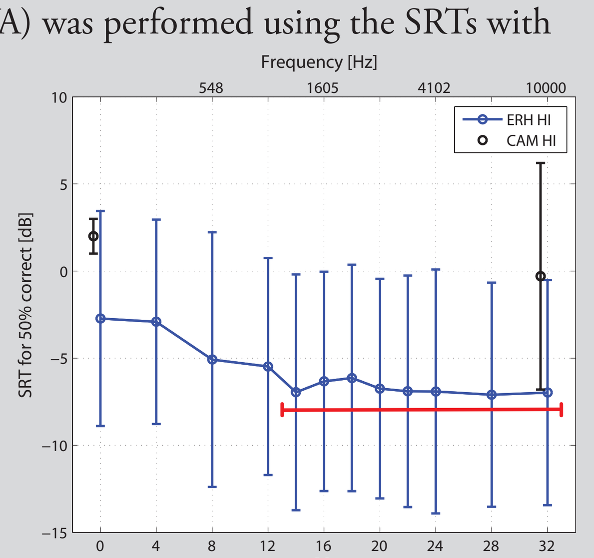


Fig 5. Mean SRTs for 50 % correct, plotted as a function of CO. Error bars show ± one standard deviation across subjects. The CO=0 and CO=32 results from Hopkins et al (2008) are indicated in the figure. The red horizontal line indicates mean values that were not statistically different.

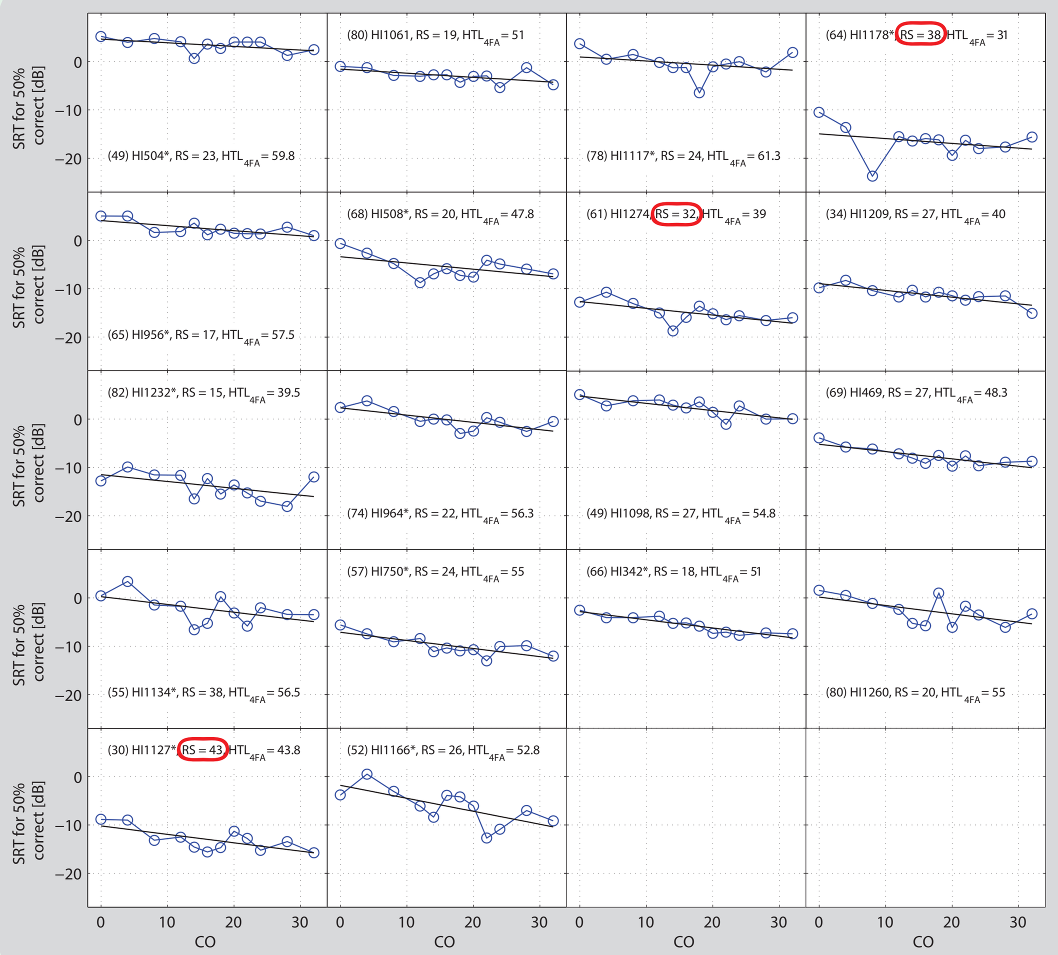


Fig 6. Individual SRTs for 50 % correct, plotted as a function of CO. Age in parenthesis. RS = reading span score. HTL_{4FA}= HTL average of 0.5k, 1k, 2k, and 4 kHz.
** indicates the 'alternative' amplification prescription*

Experiment 2

- In the TFS1 test (Moore & Sek, 2008), subjects were asked to discriminate a harmonic complex tone, with fundamental frequency (F0) = 100, 200 or 400 Hz, from a similar tone in which all components were shifted up by the same amount in Hertz, ΔF.
- To reduce cues relating to differences in the excitation patterns of the two tones, tones containing many components were used, and the tones were passed through a fixed bandpass filter centered on the higher unresolved harmonics (here: the 11th component, N=11); see the two right-hand panels of Fig 7.
- The envelope repetition rate of the two sounds is the same (e.g., 100 Hz), so the difference in pitch is assumed to occur because of a difference in the TFS of the two sounds.
- *Adaptive and fixed procedure:* An adaptive procedure was used to estimate the value of ΔF required for threshold; this was taken as the geometric mean value of ΔF at the last six reversal points. The maximum possible shift is 0.5F0. If the maximum possible shift was reached three times during a run, the shift was fixed at 0.5F0 and 20 more trials were presented. A score of 15 (75 % correct) or higher is significantly better than chance (p < 0.021) and probably indicates some ability to use TFS.

The test were conducted in three steps:

1. F0 discrimination. Task training to familiarize the subjects with the task (F0)=100 Hz. See left panels of Fig. 7.
2. Bandpass stimuli. Training with "resolved" components on TFS1 task (N=5). (F0) =100, 200 and 400 Hz.
3. Bandpass stimuli. Test with unresolved components on TFS1 task (N=11). (F0) =100, 200 and 400 Hz.

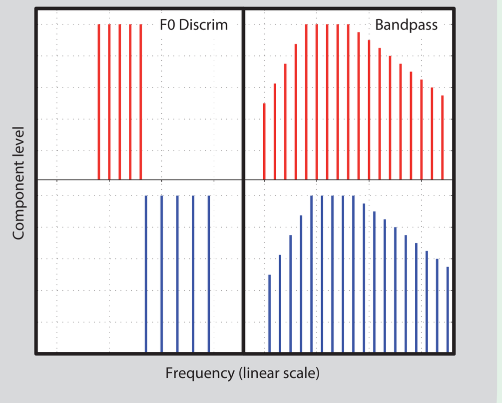


Fig 7. Schematic spectra of the stimuli in Experiment 2

	F0 discrim N=11	TFS threshold ("resolved") N=5			TFS threshold (unresolved) N=11		
F0 (Hz)	100	100	200	400	100	200	400
Cf (Hz)	1100	500	1000	2000	1100	2200	4400
HI750	**4.8 Hz**	50%	**45.8 Hz**	50%	50%	50%	55%
HI956	**4.5 Hz**	35%	**80%**	**51.2 Hz**	50%	40%	55%
HI964	**3.6 Hz**	**37.1 Hz**	**9.7 Hz**	**141.7 Hz**	45%	55%	50%
HI1061	**6.5 Hz**	**9.4 Hz**	**27.2 Hz**	25%	25%	50%	45%
HI1098	**3.4 Hz**	65%	60%	35%	35%	65%	30%
HI1127	**2.5 Hz**	**26.6 Hz**	**9.7 Hz**	**8.5 Hz**	45%	45%	40%
HI1166	**7.8 Hz**	25%	31.6 Hz	25%	40%	45%	25%
HI1178	**4.5 Hz**	**13.6 Hz**	**4.6 Hz**	**13.2 Hz**	30%	**21.8 Hz**	65%
HI1274	**1.7 Hz**	**3.6 Hz**	**3.9 Hz**	**7.6 Hz**	**10.5 Hz**	**23.4 Hz**	65%

Table 1. Boldface indicates measurable TFS thresholds

Results

- **All subjects were able to complete the F0 discrimination task.**
- **Some subjects performed at chance level in the N=5 training task.**
- **Most subjects were unable to discriminate between the original and the frequency shifted stimuli in the N=11 task, suggesting that they could not access the temporal fine structure information. These findings replicate the findings of Hopkins and Moore (2007).**
- Poor performance by hearing-impaired subjects in the unresolved condition (N=11) cannot be attributed to poor task understanding, as better performance was recorded in the F0 discrim task and the N = 5 task using the same experimental procedure.
- Two subjects with high performance on the reading span test were able to discriminate TFS differences, suggesting a top-down component in addition to better hearing thresholds, or suggesting that the ability to use TFS is correlated with cognitive abilities. Both may reflect the general efficiency of neural processing (Moore, 2008).

Conclusions

- The results from Experiment 1 replicated the results for hearing-impaired subjects of Hopkins et al (2008). The amount of benefit gained from added TFS information varied between hearing-impaired subjects, with some showing no benefit at all.
- The results from Experiment 2 replicated the results for hearing-impaired subjects of Hopkins and Moore (2007). Listeners with moderate cochlear hearing loss show very little or no ability to use TFS information to discriminate harmonic and frequency-shifted tones.
- Possibly there is a top-down component in the ability to utilize TFS information.
- In all, this study supports the suggestion that hearing-impaired subjects have a limited ability to use TFS information in speech, particularly at medium and high frequencies.

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