Principles of modulation processing in monaural versus binaural hearing

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Introduction

Several phenomena have been investigated that facilitate the perception of masked sounds, such as binaural masking level differences (BMLD) and monaural comodulation masking release (CMR). It is assumed that both (high-frequency) BMLD and (across-channel) CMR use envelope correlation between different channels as a detection cue. Durlach [1] introduced the equalization-cancellation (EC) approach as an across-channel mechanism for explaining BMLD. EC-based models were shown to quantitatively account for many binaural listening experiments. Buus [2] suggested that an EC-type mechanism could also be appropriate to account for CMR. However, it has never been tested if such an approach is able to quantitatively predict CMR. The aim of the present study is to develop and evaluate an EC-type model in monaural modulation processing.

Model

In Durlach's EC approach, the outputs of the peripheral filters with the same centre frequency at both ears are processed. Figure 1 shows a corresponding EC-type mechanism in the monaural modulation domain. Here the outputs of the modulation filters with the same centre frequency (except the DC-component) are further processed for the two considered peripheral filters whereby the flanking band is subtracted from the signal band (cancellation-process). This leads to a noise reduction in the signal band.

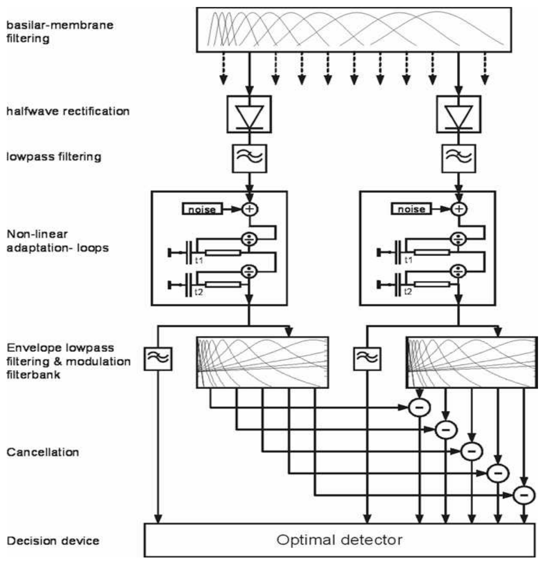

Figure 1: Block diagram of the monaural across-channel perception model. The EC mechanism is incorporated for two auditory channels at the outputs of the modulation filterbank.

No equalization process is involved for the single-flanker-band condition. In a generalized EC-type model, equalization refers to the averaging of the activity in several flanking bands whereas the cancellation is still the subtraction of this activity from the signal band.

Method

The experimental condition for testing the EC model is shown in Figure 2.

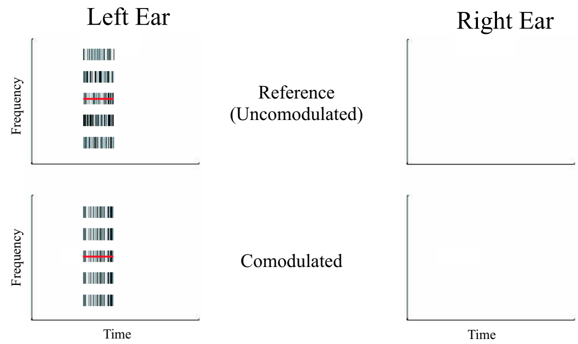

Figure 2: Two stimuli configurations to measure across-channel CMR for four flanker bands. The patterned boxes illustrate the noise maskers and the horizontal line the signal.

The signal was a 1000 Hz pure tone with a duration of 187.5 ms. The maskers consisted of 5 bands which were centered at 250, 500, 1000, 2000 and 4000 Hz covering a range of 4 octaves. In the reference condition the maskers had random envelopes whereas in the comodulated condition the maskers were frequency shifted versions of the masker at 1000 Hz. The bandwidths of the maskers was 25, 50 and 100 Hz. The CMR was calculated as the difference in threshold between the reference and the comodulated situation. An adaptive, three-interval, 3-AFC procedure was used in conjunction with a 2-down 1-up tracking rule to estimate masked thresholds throughout all the experiments.

Results

Figure 3 shows the results for the model (filled symbol) and two subjects (open symbols).

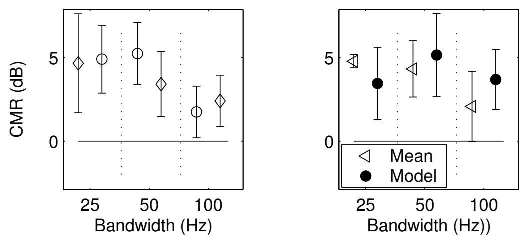

Figure 3: Left: CMR for two subjects and for different bandwidth. Right: CMR model predictions and mean

How-ever, the model does not show the decrease of CMR with increasing bandwidth (from 25 to 100 Hz) as reflected in the experimental data. The predicted values for CMR stay within 1 dB.

Discussion

The modelling results show that an EC-type model is, in principle, able to predict across-channel CMR. In order to illustrate the responsible mechanisms within the model, Figure 4 shows the output of the modulation filters at the signal band for a 300-ms noise input stimulus.

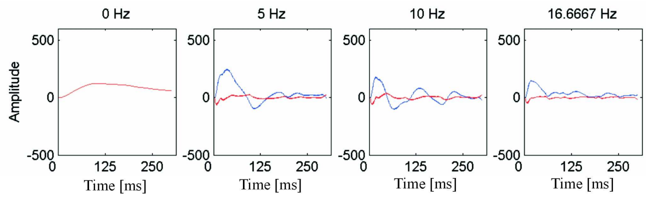

Figure 4: Output of modulation filters with (red line) and without (blue line) EC mechanism when stimulated with (25-Hz wide) narrowband noises.

The red and blue lines indicate the internal representation of the noise maskers with and without the EC mechanism, respectively. The frequency above each single panel denotes the centre frequency of the modulation filter. It can be seen that the application of the EC-type mechanism leads to a noise reduction since the blue function has a higher RMS value than the red function. The main noise reduction seems to takes place at the low modulation frequencies (around 5 Hz) such that the information stored in these low-frequency channels is crucial to facilitate detection.

What cannot be predicted by the current model is the effect of auditory grouping on CMR as observed e.g. in [3]. Since it is assumed that BMLD and CMR underlie similar principles the question is whether BMLD is also sensitive to auditory grouping. Figure 5 shows the stimulus configuration that was used to investigate grouping effects in

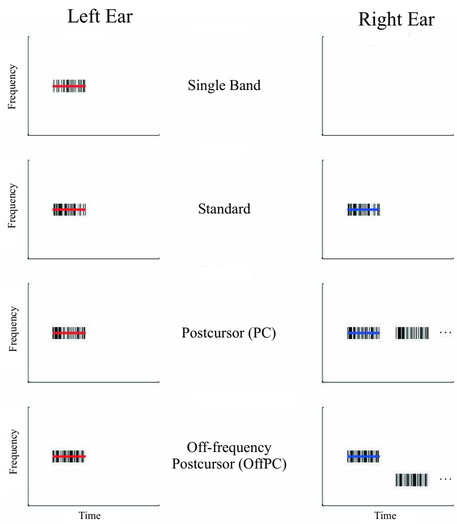

Figure 5: Four stimulus configurations used to investigate auditory grouping on BMLD. The patterned boxes represent the maskers. A red solid line represents the signal with a 0˚ phase shift and a blue solid line a signal with 180˚phase shift

binaural listening. The signal duration was 187.5 ms. The single-band condition serves as a reference and BMLD is calculated as the difference between the thresholds of this condition and the following conditions. In the standard condition (STA), the maskers are the same at both ears and the signals are out of phase. In the postcursor condition (PC),

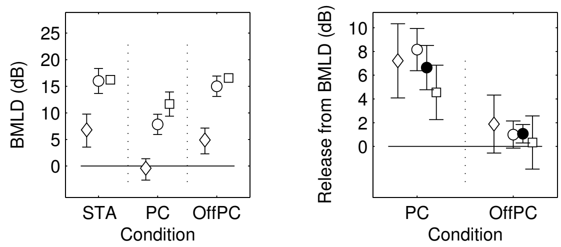

Figure 6: Left: BMLD for three subjects and three conditions (STA, PC, OffPC) for a signal frequency of 5000 Hz. Right: Release from masking for the three subjects by auditory grouping for two conditions (PC, OffPC) .The mean value across subjects is represented by the full circles.

the on-frequency band was followed by 4 postcursors who had the same duration as the on-frequency maskers and were divided by gaps of 67.5 ms. In the off-frequency postcursor condition (OffPC), the postcursors were presented at a frequency of 2815 Hz instead of 5000 Hz. The results for the auditory grouping experiment for a signal frequency of 5000 Hz for three subjects are shown in the left panel of Figure. The right panel shows the release of masking introduced by the postcursors. The release is calculated as the difference between the BMLD for the standard condition and the two postcursor conditions. The data show a considerable variability across subjects in the amount of BMLD. The main effect is that the presentation of the on-frequency postcursors clearly reduces the amount of BMLD measured in the standard condition.

Summary and conclusions

- The across-channel model including an EC-mechanism quantitatively accounts for the main effects of across-channel CMR. Slow envelope fluctuations seems to be crucial for CMR.
- High-frequency BMLD is sensitive to auditory grouping constraints. Thus, it is at least partly based on envelope processing cues that most likely take place at a central stage of processing.

References

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