Comodulation masking release with time-varying spectra

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Introduction

Many natural sounds including speech show common temporal level fluctuations in different frequency regions, i.e. they are comodulated. A psychoacoustical effect related to our sensitivity to such comodulation is "Comodulation Masking Release" (CMR) [1][6]. In CMR experiments, it is found that thresholds of a sinusoidal signal masked by noise are lower if the masker is comodulated compared to a masker with uncorrelated level fluctuations in different frequency regions. So far, CMR has been investigated using stationary spectra. However, natural sounds often show, apart from temporal comodulation, also non-stationary spectra and spectro-temporal modulations [3]. The auditory system seems to be sensitive to those modulations [4]. The present study investigates if CMR is still observed when the stimuli have these other features of spectral and spectro-temporal modulations in addition to comodulation.

A typical CMR paradigm is the flanking-band type of experiment where a sinusoidal signal is masked by one or more narrow-band maskers (usually band-pass filtered noises). In general, three masker conditions are compared. The spectrogram of these conditions are shown in figure 1.

In the reference condition (RF, top left panel) only a narrow masker component centered at the signal frequency is present. This masker will be referred to as the on-frequency masker (OFM) in the following. In the comodulated condition (CM, bottom panel of figure 1), masker bands having the same intensity fluctuations (envelopes) are added to the OFM at different frequencies. These additional masker bands are commonly referred to as flanking bands and hence the name of this CMR paradigm [6]. In the uncorrelated condition (UN, top right panel of figure 1), the same number of masker bands are present as in the comodulated condition, with the difference that the bands have uncorrelated envelopes.

There are two definitions of CMR. According to the first definition the comodulated condition is compared with the reference condition. The resulting masking release is referred to as CMR_{RF-CM}. The second definition of CMR is to relate the threshold obtained in a comodulated condition to the threshold of the uncorrelated condition, i.e. to compare two conditions with the same spectra but different envelope correlations of the masker bands. The resulting masking release is referred to as CMR_{UN-CM}.

As mentioned in the beginning, natural sounds show time-varying spectra and more complex modulations than purely temporal modulations. In order to test the robustness of CMR, the classical flanking band type of CMR experiment is modified using stimuli with non-stationary spectra and spectro-temporal modulations. In the first experiment, the CMR is measured for sweeps rather than tones, i.e. the signal and the center frequencies of the masker bands are time varying. In the second experiment, the flanking band paradigm is extended towards spectro-temporal modulation by introducing a spectral component into the modulation.

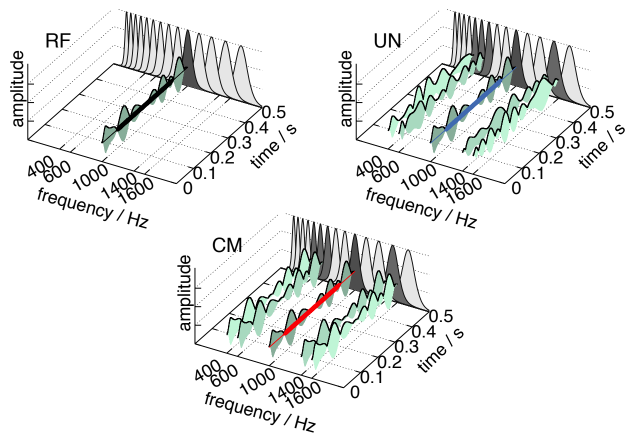

Figure 1: Spectrograms of the masker conditions used in classical CMR flanking band paradigm shown in a similar way as in, e.g., [5]: reference condition (RF, top left), uncorrelated condition (UN, top right), and comodulated condtion (CM, bottom). In each panel, the masker components are shown in greenish grey. Due to the limited temporal resolution of the plot essentially the envelope of the masker bands are seen which are highlighted with a black lines. The signal is shown in the same color that was used for the data representation of thresholds in these conditions in the following figures. In the back, a filterbank mimicking the frequency-place transformation at the level of the cochlea is shown.

General Methods

Four normal hearing subjects (between 20 and 27 old) participated in the experiment. All had at least two hours of training with similar stimuli. An adaptive three interval alternative forced choice procedure with a 1up-2down rule was used to estimate thresholds. Six runs were recorded and the last four runs were averaged. The experiment was carried out in a double walled sound proof chamber. The stimuli were generated using Matlab with a sampling rate of 44100 Hz and presented via Sennheiser HD650 headphones. They were presented in intervals of 500 ms including a 50 ms rise and fall time.

Experiment 1

Stimuli

The masker consisted of one (RF condition) or five noise bands (UN and CM condition). Each noise band had a level of 60dB SPL and was created by multiplying a low pass noise with a sinusoid or with a logarithmic sweep. For the comodulated condition, the same 12-Hz wide low-pass noise was used, whereas for the uncorrelated condition, a new lowpass noise was generated for each band. The carrier sweep was calculated according to equation 2. The half-time center frequency of the signal and the OFM was 1000 Hz, the half-time center frequencies of the FB 400, 600, 1400 and 1600 Hz.

$$x(t) = sin(2\pi \int f(t)dt) \quad (1)$$

$$f(t) = f_{begin} \cdot \left(\frac{f_{end}}{f_{begin}}\right)^{\frac{t}{t_{end}}} \quad (2)$$

Thresholds were measured for the three masker conditions (RF, UN, CM) for thirteen sweep rates. As an example, spectrograms for some stimuli are shown in figure 2. The sweep rates used in the experiment were: 0, ±1/3, ±1, ±1.5, ±2, ±2.5 and ±3 octaves per 500ms interval relative to 1000 Hz. Negative sweep rates correspond to downward sweeps, positive sweep rates to upward sweeps. The signal had the same sweep rate as the masker and was spectrally centered in the OFM.

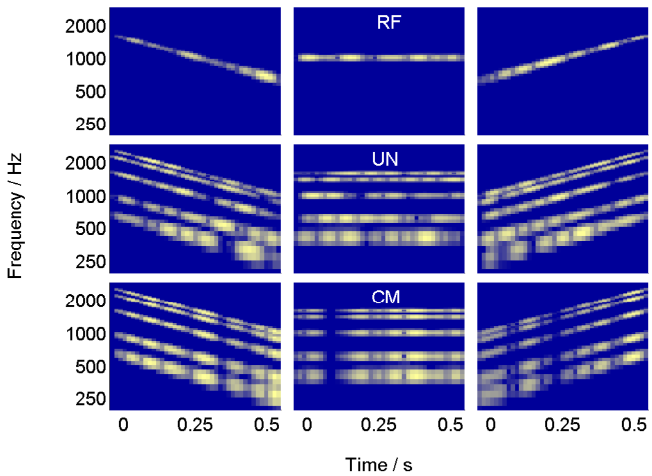

Figure 2: Spectrograms of the maskers used in the first experiment with stationary (middle column) and non-stationary spectra (left and right column). For non-stationary spectra the maskers had sweep rate of ± 1.5 oct/interval. Upper panels: RF conditions, middle panels: UN conditions, lower panels: CM conditions.

Results

Figure 3 shows average thresholds for all four subjects for the RF, UN and the CM conditions as a function of the sweep rate. The left panels show the data and CMR for downward sweeps, the right for upward sweeps. The RF thresholds are hardly influenced by the sweep rates. The UN and CM thresholds increase with increasing

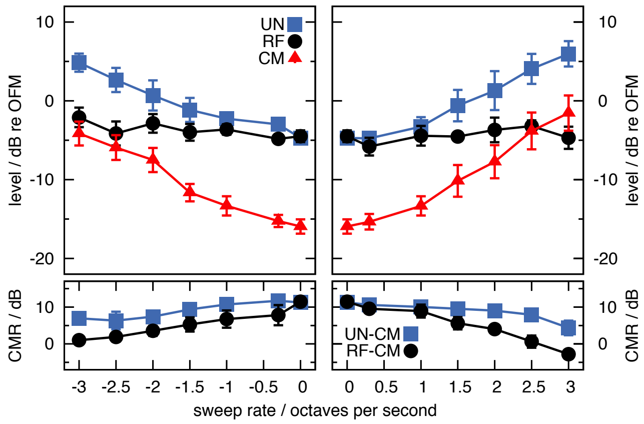

Figure 3: Upper panels: Average thresholds for the four normal hearing participants for the RF (black circles), UN (blue squares) and CM (red triangles) conditions as a function of the sweep rate. Thresholds are in expressed in dB relative to the level of the on-frequency masker (OFM). Lower panels: Comodulation masking release (CMR), i.e. the difference between the RF and CM ((RF-CM), black squares) and the UN and CM condition ((UN-CM), blue circles).

sweep rate. This causes a decrease in CMR_{RF-CM} from 11dB in the stationary condition to 0 dB for 3 octaves per second upward sweeps. For a sweep rate of -3 octaves per second, the CMR(RF-CM) is negative. The CMR_{UN-CM} decreases by 5 dB for the highest sweep rate. A residual CMR(UN-CM) of 6 dB could be found even for the highest sweep rate. In general, sweep direction had little effect on thresholds and CMR.

Experiment 2

Stimuli

In the second experiment, the sweep rate was kept constant at 1/3 octaves per interval. Various spectro-temporal modulations (STM) were introduced as shown in figure 4. The different spectro-temporal modulation were characterized by different spectro-temporal slopes $\Delta f/\Delta t$ (see top right panel). Slopes were generated by shifting each flanking band of a CM condition in time, before multiplication with the sweep. The time shift was such that minima and maxima of noise bands were spectro-temporally aligned. For upward sweeps used here, the flanking bands above the signal frequency were shifted backwards and the flanking bands below the signal frequency were shifted forward. The timeshifts were calculated according to equation 3.

$$\Delta t = \frac{log(f_{signal}) - log(f)}{m + 1/m} \quad (3)$$

where Δt is the timeshift in seconds, f_{signal} the half-time signal center frequency, f the half-time center frequency of the flanking band that is shifted in time and m denotes the absolute value of the slope. The resulting time shifts for the slopes used are shown in table 1

Results

The average results for all subjects for the second experiment are shown in figure 5. Thresholds increased with

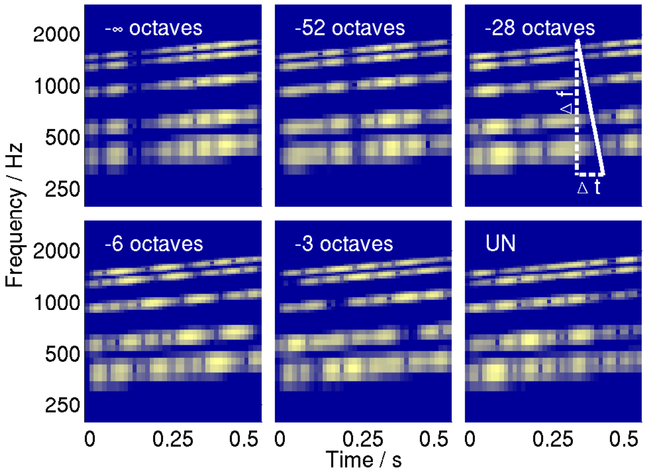

Figure 4: Spectrograms of the maskers used in the second experiment. CM and UN conditions are shown in the upper left and the lower right panel, respectively. The other panels show spectro-temporal modulations with various slopes. Definition of the slope is visualized in the upper right panel.

	-3 oct/s	-6 oct/s	-28 oct/s	-52 oct/s
1000 Hz	0 ms	0 ms	0 ms	0 ms
400 Hz	349 ms	174 ms	35 ms	17 ms
600 Hz	194 ms	97 ms	19 ms	10 ms
1400 Hz	-128 ms	-64 ms	-13 ms	-6 ms
1600 Hz	-179 ms	-89 ms	-18 ms	-9 ms

Table 1: Time shifts for different spectro-temporal patterns for each masking band. The columns show time shifts for spectro-temporal patterns with different slopes.

decreasing slopes. The spectro-temporal modulation abolisheed CMR obtained in a comodulated condition. The CMR_{UN-STM} was reduced to zero for a slope of -6 octaves per second.

Discussion

The first experiment shows two main results. First of all, the sweep rate has no influence on the detectability on a signal masked by a single noise band, while it does for maskers including flanking bands. This might be explained by the time for which a signal stays within one auditory filter. This time is reduced with increasing sweep velocities. This obviously can be compensated by integrating the information of several auditory filters if only one spectral component at a time is present i.e in the RF condition. For maskers including flanking bands this is not possible. One hypothesis is that due to the fact that several spectral components are present simultaneously, there is a spectral uncertainty in which auditory filter to look for the signal. The second important result of the first experiment is that a residual CMR can be found for sweeping stimuli when two conditions with the same spectrum (UN and CM) are compared. The mechanism responsible for CMR_{UN-CM} seems to be working also with non-stationary spectra. This supports the hypothesis that, in order to investigate

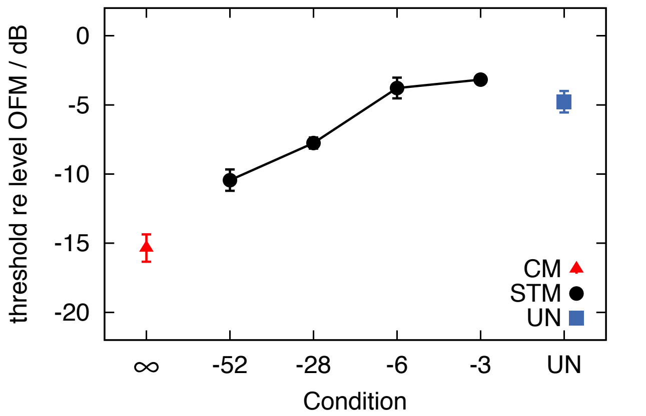

Figure 5: Average thresholds for four normal hearing participants for several spectro-temporal modulated conditions for a sweep rate of 1/3 octaves per interval. Red triangle: CM condition, corresponding to a spectro-temporal modulation with a slope of $-\infty$. Black circles: STM conditions as a function of the slope in octaves per second. Blue square: UN condition. Thresholds are in dB relative to the level of the on-frequency masker (OFM).

the benefit due to comodulation, conditions with the same spectrum should be compared [5].

Changing the slope of the comodulation direction is realized by introducing time shifts to each flanking band. These time shifts seem to abolish the masking release obtained in a comodulated situation. Thus, although the auditory system seems to be sensitive to spectro-temporal modulations, changes in this cue can not be used to improve signal detectability.

References

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