# Simulating Relative Masking Levels for Narrowband Chirp Stimuli using the Computational Auditory Signal Processing and Perception (CASP) Model

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## Introduction

In audiological examinations, there is a risk of cross hearing by examining patients with asymmetric hearing loss. In such cases, the hearing of the signal presented in the ipsilateral worse ear through the better contralateral ear has to be prevented by presenting a masking sound in the contralateral ear. The level of this masking sound necessary to mask the signal depends on the used signal. The present study focusses on the signals used in evoked response audiometry, where the risk of cross hearing also has to be considered. Evoked response audiometry commonly uses sequences of short signals. The perception of these sounds is different to pure tones and therefore, the necessary masker level for these signals has to be studied explicitly. Experimental data on masking of some short time signals have already been reported [1]. The present study focusses on narrowband chirps. Psychoacoustic data of the masking of theses sounds were presented at the DAGA 2024 [2].

The purpose of the present study was to investigate to what extent the masking can be predicted. Predicting psychoacoustic data with auditory models can give an insight to different mechanisms concerning sound perception. There is a huge variety of auditory models fitted for different psychoacoustic phenomena. One well established model concerning different masking or modulation phenomena is the computational auditory signal processing and perception (CASP) model, first described by Dau and co-authors [3]. By varying different model parameters, it is possible to investigate which cues the model uses to predict the psychoacoustic experiment. The present study investigated the ability to predict previously presented psychoacoustic data using the CASP model.

## Model

A schematic diagram of the basic preprocessing stages of the CASP model is shown on the left of figure 1. This series of

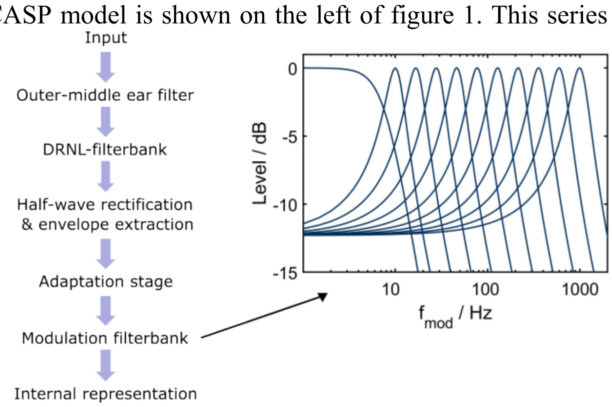


**Figure 1:** Left: Different preprocessing stages of the CASP model. Through these stages an internal representation of an input signal is achieved. Right: Filter characteristics of the modulation filterbank.

preprocessing stages mimics basic auditory signal processing mechanisms. Additionally, on the right of figure 1 the filter characteristics of the modulation filterbank are shown. Such a filterbank was not included in the first description of the model [3] but was implemented later on [4] to analyze amplitude changes of the signal envelope. The present study uses the implementation by Jepsen et al [5].

After these preprocessing stages, an internal representation of an input signal is calculated. Such an internal representation represents an activity pattern over time, auditory frequency and modulation frequency contained in the input signal. The internal representation of a current signal interval is cross correlated with an internal representation of the target signal at a suprathreshold level. This so-called template is determined for every new threshold determination.

## Methods

### Signals

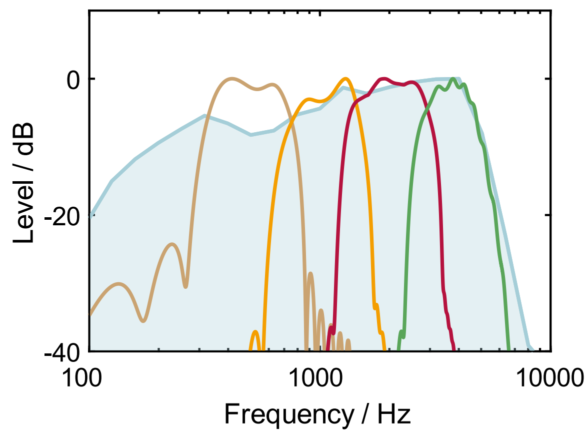


**Figure 2:** Magnitude spectra of the four narrowband chirps and the broadband noise convolved with impulse response of the insert phones used in the psychoacoustic experiment.

In figure 2, the magnitude spectra of the four narrow band chirps investigated in this study with the center frequency of 500 Hz (light brown), 1000 Hz (yellow), 2000 Hz (dark red) and 4000 Hz (green) as well as the broadband noise (light blue) to mask the chirps are shown. Due to the influence of the transfer characteristics of the insert phones used in the psychoacoustic study (Radioear IP30, 50 Ω, Middlefart, Demark), the spectra were calculated from the signals convolved with the impulse response of the insert phones. The spectrum of the broadband noise is smoothed by analyzing it in one-third octave bands.

The masker level was measured as an unweighted sound pressure level. The chirp level was calibrated in dB nHL (normalized Hearing Level) according to given calibration values [6]. Due to the principle description of the model, the masker level was fixed to 60 dB SPL and the chirp level was adjusted. The repetition rate of the narrowband chirp was 40 Hz. A duration of 500 ms was used for the presentation interval, including $\cos^2$ ramps of 50 ms at interval onset and offset.

**Experiment**

An adaptive 3-interval alternative forced choice experiment was simulated to investigate masking of the narrowband chirps within the model. Using a 1-up 2-down rule, the chirp level was adjusted in steps of 6, 3 and finally 1 dB. The mean of 6 turning points starting with 1 dB step size was defined as masked threshold of the chirp. The experiment started with a chirp level of 10 dB below the masker level. For each narrowband chirp, the masked threshold was simulated 36 times.

Based on psychoacoustic results, the template was derived with the chirp level set to 20 dB below the masker level. This level was well above the measured threshold. The full DRNL filterbank as well as the full modulation filterbank were included in the simulation. The lowpass of the modulation filterbank had a cut-off frequency of 7.5 Hz. No modifications of the latest description of the model [5] had been made.

Further investigation of the influence of the modulation filterbank were carried out by varying the number of modulation filters included in the simulation. For this purpose, simulations were run by increasingly limiting the highest filter of the modulation filterbank until only the lowpass was left. Again, for each chirp center frequency, the simulation was repeated 36 time. For simulations with low number of modulation filters, the level of the chirp for the template was adjusted to 10 dB or 0 dB below the masker level. This was the case for the simulation with the modulation filters up to 27 Hz and 46 Hz or the 16 Hz center frequencies and when only the lowpass filter was used.

A group of 12 normal hearing participants took part in the previously presented psychoacoustic experiment [2]. The age of the participants ranged from 21 to 50 years (median 28.5 years). Contrary to the simulations, the chirp level was fixed to 30 dB nHL and the masker level was adjusted with the 1-up 2-down rule using the same step sizes. The masker level necessary to mask the chirp was defined as the mean of 6 turning points starting with 1 dB step size. For each chirp frequency the masker levels of three repetitions were averaged per participants and finally the mean over all participants was determined.

## Results

In the following, the results are shown as a relative masking level, e.g. the difference of masker level in dB SPL to chirp level in dB nHL. Figure 3 shows the simulation results and the results of the previously presented psychoacoustic experiment [2]. The filled blue diamonds are the mean over the 36 repeated simulations per chirp frequency together with the standard deviation. The open blue circles are the mean over the 12 participants in the psychoacoustic study. Error bars indicate plus and minus one interindividual standard deviation of the mean.

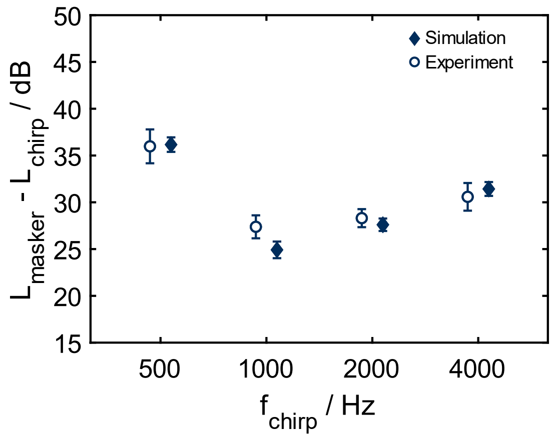


**Figure 3:** Relative masking level for narrowband chirps. The mean of the 36 runs per simulation are shown as filled diamonds with their standard deviation. Open circles indicate the psychoacoustic data as the mean over the 12 participants and the standard deviation.

The relative masking levels show a dependency on the center frequency of the chirp. The relative masking levels predicted by the CASP model range from 25 dB for the 1000 Hz chirp to 36 dB for the 500 Hz chirp. The psychoacoustic data lies between 27 dB for the 1000 Hz chirp and 36 dB for the 500 Hz chirp. In the psychoacoustic experiment, the three high frequency chirps show similar relative masking levels with differences of less than 3 dB. In contrast, the CASP model underestimates the relative masking level for the 1000 Hz chirp by 2.5 dB resulting in higher differences of about 5 dB between the three high frequency chirps.

Despite slight changes in the experimental paradigm (signal varying vs. masker varying), the simulation results are in good agreement with the psychoacoustic results. It should be emphasized that no modifications of the current form of the model [5] were necessary to achieve these results.

Figure 4 shows the simulation results for the investigation of the influence of the modulation filterbank. Plotted as open diamonds are the mean over the 36 repetitions with the

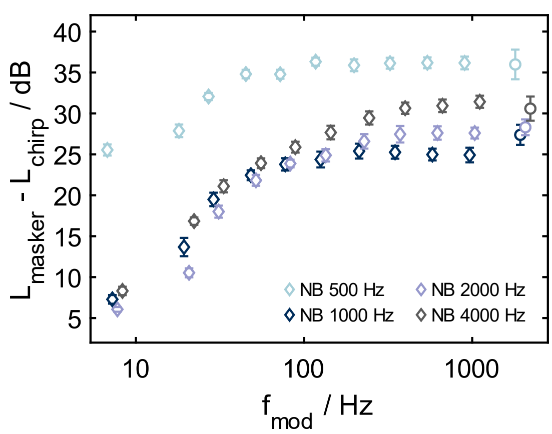


**Figure 4:** Relative masking level for narrowband chirps plotted against the highest filter frequency of the modulation filterbank included in the simulation. The open diamonds are the mean over the 36 runs per simulation and the open circles on the far right indicate the psychoacoustic results. Different colors correspond to the different chirp frequencies.

standard deviation. The different colors indicate the results for the 4 different narrowband chirps, as indicated in the legend. For comparison, the results of the psychoacoustic experiment are plotted as open circles at the far right of the figure with their color corresponding to the narrowband chirp frequency. Furthermore, the simulation results of the individual chirps are only shown for the modulation frequencies which are below ¼ of the auditory frequency range of the chirp. These criteria lie in the principle description of the model.

Each chirp shows an increase in relative masker level with an increasing coverage of modulation frequencies in the simulation. Due to the internal limitation of modulation frequency considered in the cross correlation of the model to ¼ of the center frequency of the auditory filter, the narrowband chirps behave differently in this investigation. For the 500 Hz chirp, the psychoacoustic results are already met by considering only modulation frequencies up to about 77 Hz. However, the auditory frequency range of this chirp is not covered by modulation filters above 250 Hz center frequency. This could explain the unchanged results above 100 Hz modulation frequency. On the contrary, the psychoacoustic results for the 4000 Hz narrowband chirp are only met if the whole modulation filterbank is considered in the simulation.

## Conclusion

In the present study, the masking of narrowband chirps predicted by a psychoacoustic model was investigated. The model could predict the results of a previously presented psychoacoustic study of the same experiment and showed only small deviations.

## Literature

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