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Characterizing binaural sensitivity to dynamic interaural level differences

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Introduction

The binaural system is usually described as being sluggish and there are many reports in the literature of time constants of binaural temporal windows, ranging from about 10 ms to 250 ms, depending on the experimental method. A recent physiological study [1] reported some neurons that respond to fluctuations in interaural correlation and encoded rates to at least an order of magnitude higher than the detectable rates reported in psychoacoustic studies using similar stimuli. In the current study, two psychoacoustic experiments were performed in order to determine if the binaural system is able to make use of the available temporal information or if a simple lowpass filter is sufficient to describe the performance of human listeners in binaural detection tasks with dynamic interaural cues.

Methods

High frequency stimuli, centered at 5 kHz, were used for both experiments so that only the envelope of the signal and not its fine structure should be available as input to binaural processors. The test subjects were presented with three binaural sound intervals over headphones in a sound attenuating booth. The signals had a duration of 500 or 1000 ms, depending on the signal modulation frequency. In the first experiment, a binaural extension of experiments from [2] and [3], all three intervals had a sinusoidal amplitude modulation (SAM) imposed on pure-tone or interaurally uncorrelated narrowband noise (3, 30, or 300 Hz wide) carriers. In two of the intervals (reference condition), the SAM was diotic, while in a randomly selected signal interval, the SAM had an interaural phase shift of π, as shown in Equation 1.

$$
\begin{aligned}
x_L &= (1 + m \sin(2\pi f_s t + \phi))c_1(t) \\
x_R &= (1 + m \sin(2\pi f_s t + \phi + \pi))c_2(t)
\end{aligned}
\tag{1}
$$

The test subject had to identify the interval with the antiphasic SAM in a 3-alternative, forced-choice experiment. Since all three intervals were similarly amplitude modulated, detection could only be performed through the combination of modulation phase information in the binaural system. The modulation depth m was varied adaptively using a 2-down, 1-up paradigm until the threshold was determined as the median of six reversals with a step size of 1 dB. The data shown in the results are the mean and standard deviation of four normal-hearing test subjects, including the authors, with four repetitions each.

In the masked discrimination experiment, a pure-tone carrier was amplitude modulated with an interaurally uncorrelated narrowband noise maskers and a sinusoidal signal as shown in Equation 2. Again, the reference intervals were modulated with the same sinusoidal signal, only without an interaural phase difference.

$$
\begin{aligned}
x_L &= (1 + n_1(t))(1 + m \sin(2\pi f_s t + \phi))c(t) \\
x_R &= (1 + n_2(t))(1 + m \sin(2\pi f_s t + \phi + \pi))c(t)
\end{aligned}
\tag{2}
$$

The bandwidth of the masker was fixed for each signal modulation frequency at a half-octave centered at the signal frequency. The power of the masker was also fixed at -10 dB, and the modulation depth required for discrimination with a fixed signal modulation frequency was measured for a range of masker center frequencies. This experiment is a binaural extension of a monaural experiment from [4].

Results

The measured thresholds required for discriminating between interaurally antiphasic and homophasic SAM when imposed on pure-tone and narrowband noise carriers are shown in Figure 1. The thresholds with a pure-tone carrier ($\times$) show a lesser sensitivity (i.e. greater modulation depth required for detection) than corresponding monaural thresholds. The thresholds also increase with increasing modulation frequency at a rate of about 1.5 dB/oct. These thresholds are similar to those reported in [3].

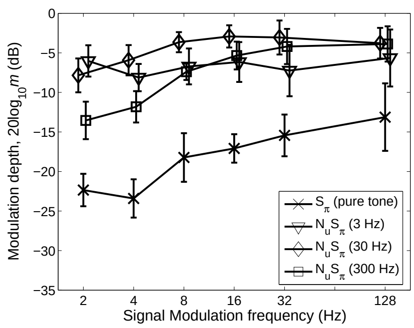

Figure 1: Modulation depths required for discrimination of interaurally antiphasic AM from homophasic AM imposed on pure-tone ($\times$) and 3 Hz- ($\bigtriangledown$), 30 Hz- ($\diamond$) and 300 Hz-wide ($\square$) interaurally uncorrelated noise bands.

When using uncorrelated narrowband noise carriers, the inherent interaural fluctuations of the carriers themselves make it more difficult to detect imposed AM, which can be seen in the overall increase of the thresholds for the three noise carriers in Figure 1. The amount of masking resulting from those inherent carrier fluctuations can be calculated by looking at the difference in threshold when using the noise carriers and the pure-tone carrier. This difference is plotted in Figure 2. The masking curve with a 3 Hz-wide carrier starts high for low signal modulation frequencies and decreases rapidly to an asymptotic value, while that for the 30 Hz-wide carrier starts at about the same level of masking and stays high until above 32 Hz, and the masking for the 300 Hz-wide carrier starts at a lower level for the 2 Hz signal modulation and remains fairly flat over the entire measured frequency range. The shapes of these curves are similar to the corresponding masking curves measured monaurally in [2], but are generally flatter and have a higher DC-offset at about 8 dB of masking. This could indicate similar bandpass tuning in the binaural system as proposed for the monaural system in [2] only with broader tuning.

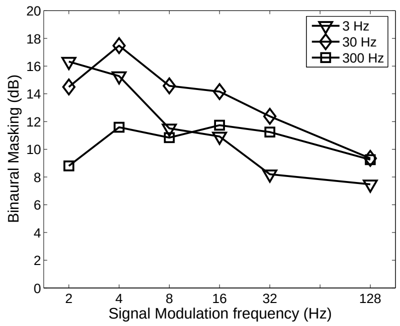

Figure 2: Masking level caused by the intrinsic interaural fluctuations of the 3 Hz- (▽), 30 Hz- (◇) and 300 Hz-wide (□) interaurally uncorrelated noise bands. Calculated as the difference between the thresholds measured with noise carriers and that measured with the pure-tone carrier.

The measured masked discrimination thresholds when using a narrowband noise AM masker are shown in Figure 3. These threshold curves show a bandpass tuning centered around the signal frequency with a slow highpass roll-off and a faster lowpass roll-off. The bandwidth of this tuning is about twice as large as the corresponding tuning reported in [4] for the monaural system.

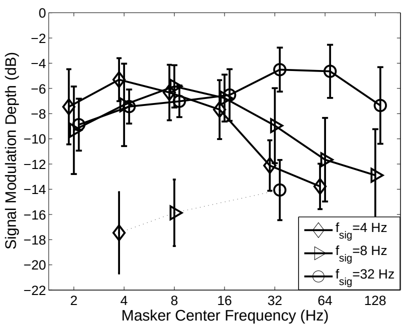

Figure 3: Modulation depths required for discrimination of interaurally antiphasic AM from homophasic AM imposed on a pure-tone carrier in unmasked (dashed line) and masked (solid lines) conditions. Measurements made with a fixed signal AM frequency of 4 (◇), 8 (▷) and 32 Hz (◯) and uncorrelated narrowband noise masker with fixed power and bandwidth for a range of masker center frequencies.

Model Simulation

The same masked detection experiment was performed using the binaural model from [5] as an artificial listener. This model uses a sliding integrator window, which acts as a lowpass filter, to account for binaural sluggishness. The predicted masking levels (i.e. difference of masked and unmasked discrimination thresholds), normalized for signal center frequency, are shown in Figure 4. These predictions show a very slight increase in masking at the signal frequency, but then show an increase in masking for higher masker center frequencies, as opposed to the roll-off seen in Figure 3. This confirms that a lowpass filter model can not predict the tuning seen in the experimental results and suggests further development for this model using a bandpass filterbank similar to the monaural filterbank from [2].

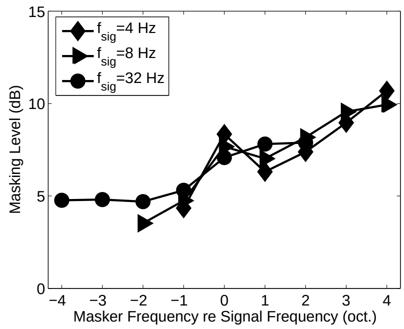

Figure 4: Model simulation of the same experiments shown in Figure 3 using the model from [5]. Data are plotted as masking level (i.e. masked threshold minus unmasked threshold) vs. masker frequency relative to signal frequency in octaves.

Conclusions

There is frequency tuning in the binaural processing of fluctuations in interaural level differences which can not be accounted for by a simple lowpass filter. This indicates that the temporal resolution that has been measured in neurons that respond to binaural input may be available to higher processing centers to use to segregate sound sources. The Breebaart model [5] will be extended to account for this data.

References

[1] Joris *et al.* Auditory midbrain and nerve responses to sinusoidal variations in interaural correlation. J. Neurosci. **26** (2006), 279-289

[2] Dau *et al.* Modeling auditory processing of amplitude modulation. I. Detection and masking with narrowband carriers. J. Acoust. Soc. Am. **102** (1997), 2892-2905

[3] Stellmack *et al.* Monaural and interaural temporal modulation transfer function measured with 5-kHz carriers. J. Acoust. Soc. Am. **118** (2005), 2507-2518

[4] Ewert and Dau. Characterizing frequency selectivity for envelope fluctuations. J. Acoust. Soc. Am. **108** (2000) 1181-1196

[5] Breebaart *et al.* Binaural processing model based on contralateral inhibition. I. Model structure. J. Acoust. Soc. Am. **110** (2001), 1074-1088