Limits of binaural decoloration investigated over ERB-based spectral manipulation

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Introduction

Binaural Decoloration plays an important role in our daily perception of sound inside environments. Normally we do not have diotic listening conditions in real life. Diotic conditions for example are apparent when a sound source is recorded over a one channel microphone and listened to over headphones. In comparison, a dichotic recording can be done, for example over a two channel microphone or an artificial head. When a diotic and a dichotic presentation are compared with respect to the perceived coloration, the dichotic signal sounds usually less colored than the diotic signal. The difference between the coloration perception is referred to as Binaural Decoloration. One explanation for this effect may be that for a dichotic presentation the different spectral cues at both ears are used to balance or flatten the spectral impression [1]. The aim of this study is to investigate how far one ear can compensate for missing energy of the other ear. For this a spectral filter shape has been designed, where the transfer function is varied frequency dependent, while the other ear gains the missing energy. The filter shape are spectral modulations on the ERB-scale, which is different to the spectral shape of a room impulse response, where the modulations are linearly spaced. This allows for an analysis of Binaural Decoloration over the frequency resolution of the human hearing. Previous studies [2] [3] investigated the detection threshold of coloration, which is rather difficult for listening participants, while they have to ignore spatial changes of the signal. In this study, listening participants where asked to judge the threshold of the natural impression of the signal.

Theory

The aim of this study is to investigate the capability of the binaural hearing system to compensate for spectral modulations. While providing less energy at one ear in one or more frequency bands, the other ear gains the missing energy, thus allowing the auditory system to compensate in principle.

For the design of a spectral shape, the total energy of the left- and right ear transfer functions L, R, respectively, are made equal 1:

$$\text{Total Energy} = \frac{1}{2}(|L|^2 + |R|^2) = 1 \qquad (1)$$

An exemplary resulting shape is shown in figure 1. This shape has one-half sinusoidal oscillation (one ripple) inside one ERB-band and will further be referred to as a ripple rate of 1 / ERB. Accordingly, a ripple rate of 0.5 / ERB corresponds to one ripple spanning over two ERB-bands. As well as different ripple rates, also the frequency dependency of Binaural Decoloration will be investigated, while manipulating the signal in different frequency ranges. The main paramter that is varied to increase or reduce coloration is the amplitude of the spectral modulations.

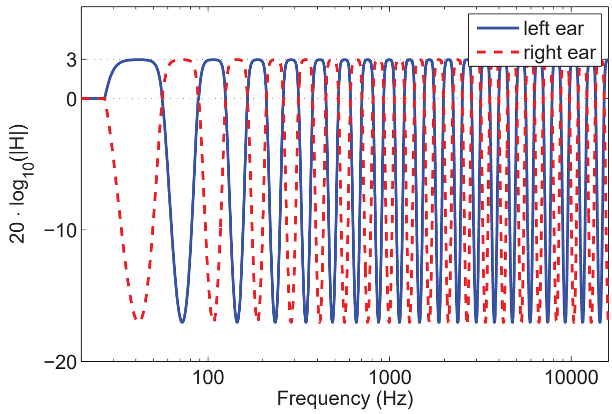

Figure 1: Logarithmic magnitude spectrum of the ERB-spaced frequency shape. The ripple rate is 1 / ERB.

This experiments aims to find the boundaries of acceptance of coloration for a diotic and a dichotic case. The diotic case will be the baseline as the difference between the diotic and the dichotic results will be refered to as "binaural advantage".

Listening Experiment: Boundaries of natural impression of coloration

In this study the following definition of coloration is used:

Coloration is the perceived spectral change attributed to the transfer function,

while listening participants where always instructed just to listen to coloration and ignore spatial impressions, resulting from the binaural manipulations. The aim was to find the the maximum amplitude of spectral modulations, at which the presented signal still gives a natural impression.

Table 1: Details of the filter manipulation

frequency ranges	[20 - 400] Hz, [400 - 1k] Hz
	[1k - 6k] Hz, [6k - 16k] Hz
	[20 - 16k] Hz (broadband)
ripple rates:	0.2 / ERB, 0.5 / ERB
	1 / ERB, 2 / ERB

Procedure

For the listening test, filter shapes as in figure 1 have been used, with the criterion from equation 1. The shape has been designed in the frequency domain and transformed into a minimum phase filter shape. Usually, for coloration experiments noise-like signals are used as stimuli. The benefit using stationary noise is that it masks the reverberant tail of a room-impulse-response, furthermore noise is a very critical signal concerning spectral differences. But this experiment aims at thresholds using natural signals for the manipulation. As a natural signal a piano (Kurzweil PC88 with no spatial effects) has been used. The conditions of the filter are listed in table 1.

For the diotic condition the left ear filter shape has been used at both ears. The parameter controlled by the listening participants was the amplitude of the manipulation. The amplitude is the maximum to minimum value of the modulations in the spectrum. For example, the amplitude manipulation from figure 1 is 20 dB.

Listening Setup

The listening test was conducted at the University of Oldenburg in a single walled listening cabin. Stimuli were presented over Sennheiser HD650 headphones at an average level of 65 dB SPL.

Participants

Six experienced listing participants took part in this study, with an average age of 32 years. To introduce the coloration to the participant, examples with several spectral manipulations were given.

Results

To interpret the results from the listening test, the amplitude of the spectral modulations of the filter is used. The standard error displays the deviation between the conditions.

The results from the frequency division from 20 Hz - 16 kHz are shown in figure 2. For the diotic case, the maximum amplitude of the listening participants was around 6 dB for all the ripple rates. In the dichotic case the very low ripple rate of 0.2 ERB lead to a lower tolerance as for the other three cases of 0.5,1,2 ERB. The mean value of manipulation was 17 dB for 0.5 ERB, 14 dB for 1 ERB and 15 dB for 2 ERB.

The results for the manipulation limited to different frequency ranges are shown in figures 3-6, each for a different ripple rate. The results for the ripple rate of 1 / ERB

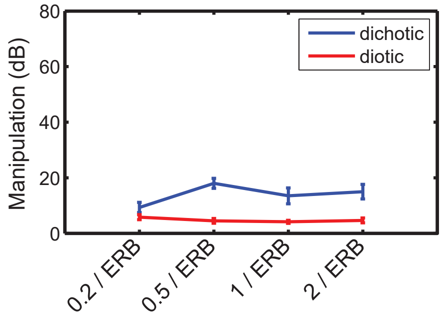

Figure 2: Results of the broadband manipulation for different ripple rates

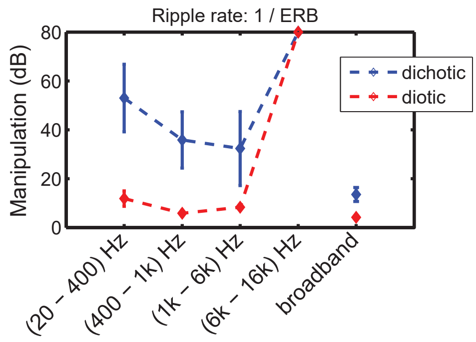

Figure 3: Frequency dependent results for a ripple rate of 1 / ERB

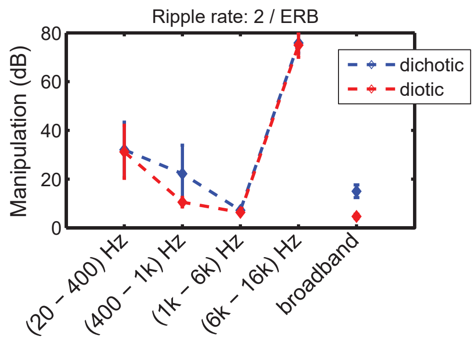

Figure 4: Frequency dependent results for a ripple rate of 2 / ERB

can be seen in figure 3. The dichotic condition lies above the diotic condition for the frequency range from 20 Hz - 6 kHz. The manipulation above 6 kHz does not turn out to sound unnatural for the diotic and dichotic condition.

As for a ripple rate of 0.5 / ERB the results in figure 5 look similar to the ripple rate of 1 / ERB. For a ripple rate of 2 / ERB (figure 4) the results look somewhat different, while the manipulation shows no longer clear higher thresholds for the dichotic case. As for very low ripple rate of 0.2 / ERB (see figure 6) the diotic conditions seems to have higher thresholds in the range of 20 Hz - 1 kHz, exceeding beyond 20 dB.

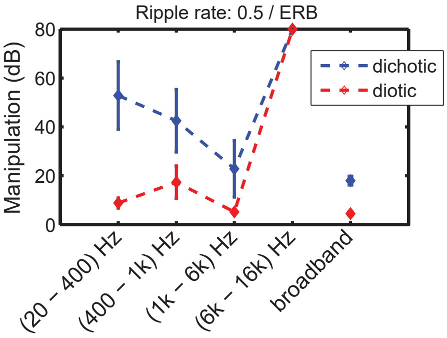

Figure 5: Frequency dependent results for a ripple rate of 0.5 / ERB

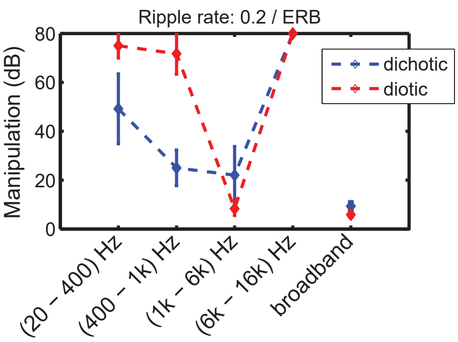

Figure 6: Frequency dependent results for a ripple rate of 0.2 / ERB

Discussion

It makes a difference in coloration perception if a diotic or a dichotic manipulation is applied. The dichotic conditions generally allows more manipulation without affecting the perceived naturalness. For the broadband manipulation a clear binaural advantage can be seen for all ripple rates. It is interesting to note that the dichotic errorbars of the broadband thresholds are rather small, as compared to the thresholds for the frequency specific manipulations. The listening participants seem to have a common cue to discriminate between a natural and unnatural sound in the broadband case. If a frequency dependent manipulation for a ripple rate of 1 / ERB and 0.5 / ERB is applied, the results are as expected, having a binaural advantage for the dichotic manipulation. It is interesting to note, that the manipulation can be relatively high, while still being perceived as natural. For the ripple rate of 2 / ERB the binaural advantage for the frequency dependent manipulation is no longer that striking, if apparent at all. This seems interesting, because a certain advantage has been measured for the broadband manipulation. The manipulation above 6 kHz seems not to turn out unnatural for all ripple rates. This might be explained with an masking effect since the piano signal has a lot of energy in the mid-frequencies and a little in the range above 6 kHz. Only the ripple rate of 0.2 / ERB the diotic gives an advantage over the dichotic signal for the manipulation up to 1 kHz. A possible explanation might be that although listening participants where instructed not to listen to spatial effects,ILD cues were consistent across wide range of frequency, resulting in a very unnatural percept.

Conclusion

In this study a method for measuring the maximally allowed amplitude of ERB spaced modulations of the magnitude spectrum of a filter was determined for both diotic and dichotic conditions. That is, the maximal amplitude was determined for which the filter, when applied to a piano signal started to sound unnatural. In the dichotic conditions, the magnitude spectrum modulations were made such that across the left and right ear, the overall energy is conserved. Results showed that for the dichotic conditions a considerable larger spectral modulation amplitude is allowed than for diotic conditions. Comparing conditions where the spectral manipulation is only applied to a limited frequency range showed considerably higher spectral amplitude modulations to be allowed than when the full spectrum was modulated.

References

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