Binaural pitch perception in hearing-impaired listeners

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Introduction

When two white noises differing only in phase in a particular frequency range are presented simultaneously each to one of our ears, a pitch sensation may be perceived inside the head. This phenomenon, called 'binaural pitch' or 'dichotic pitch', can be produced by frequency-dependent interaural phase-difference patterns. The evaluation of these interaural phase differences depends on the functionality of the binaural auditory system and the spectro-temporal information at its input. A melody recognition task was performed in the present study using pure-tone stimuli and six different types of noises that can generate a binaural pitch sensation. Normal-hearing listeners and hearing-impaired listeners with different kinds of hearing impairment participated in the experiment.

Method

14 normal-hearing and 10 hearing-impaired listeners (with different types of hearing impairment) participated in the study (for details, see [1]). For the melody recognition test, 10 well-known melodies, consisting of 16 notes of equal duration (300ms) each separated by a silence of 100ms, were played with pure-tones and six different types of binaural pitch (see also [2]). These pitch types were: Huggins pitch (HP), binaural edge pitch (BEP), binaural coherence edge pitch (BICEP), reversed BICEP (RBICEP), binaural band pitch (BBP) and binaural incoherent band pitch (BIBP), as shown in Figure 1. For details about the generation of the pitch stimuli, see [1]. After each presentation, the task of the listener was to identify which melody was played. The percentage of correct responses for each pitch type gives a measure of its salience and musicality. Listeners were trained to learn the melodies beforehand.

Experimental results

For the normal-hearing (NH) listeners, the following results were obtained: (i) Binaural pitch produced an immediate sensation; (ii) HP, BBP, and BIBP were the most salient pitches and were as musical as pure tones. BEP, BICEP, and RBICEP were less salient (see Fig. 2).

For the hearing-impaired listeners, it was found that: (i) the two subjects with diagnosed central processing deficits could not perceive any type of binaural pitch *at all*; (ii) for all other subjects, binaural pitch produced an immediate sensation as for NH subjects; (iii) all HI-subjects who could perceive binaural pitch showed lower melody recognition abilities than the normal-hearing average; (iv) HP, BBP, and BIBP were much more salient than BEP, BICEP, and RBICEP,

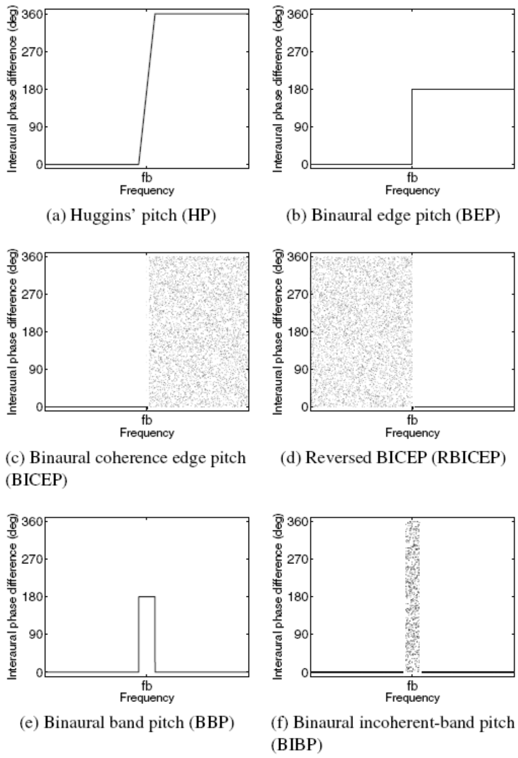

Figure 1: Six phase-difference patterns producing a binaural-pitch sensation: (a) Huggins' pitch, (b) binaural edge pitch, (c) binaural coherence edge pitch, (d) reversed binaural coherence edge pitch, (e) binaural band pitch, (f) binaural incoherent-band pitch.

and some subjects reached chance level with BICEP, RBICEP, and BEP (see Fig. 4); (v) the results were not correlated with the subjects' audiograms.

In order to investigate effects of frequency selectivity on binaural pitch perception, an additional experiment was carried out with four of the normal-hearing listeners of the study. The BICEP stimulus was modified by introducing a transition in the interaural correlation spectrum instead of a sharp edge. This is illustrated in Fig. 3. By varying the width of that transition, the internal interaural correlation spectrum (after auditory filtering) can be matched to that obtained with the original BICEP stimulus with a listener with broader auditory filters, assuming a broadening factor *b*. The corresponding results are shown in Fig. 4. The melody recognition abilities of the NH subjects decreased with the modified BICEP when *b* was increased. In contrast, the results of the melody recognition task were not changed much when an increased hearing threshold at high frequencies was simulated (instead of an assumed reduction of frequency selectivity), as indicated in Fig. 4 as "HF-loss".

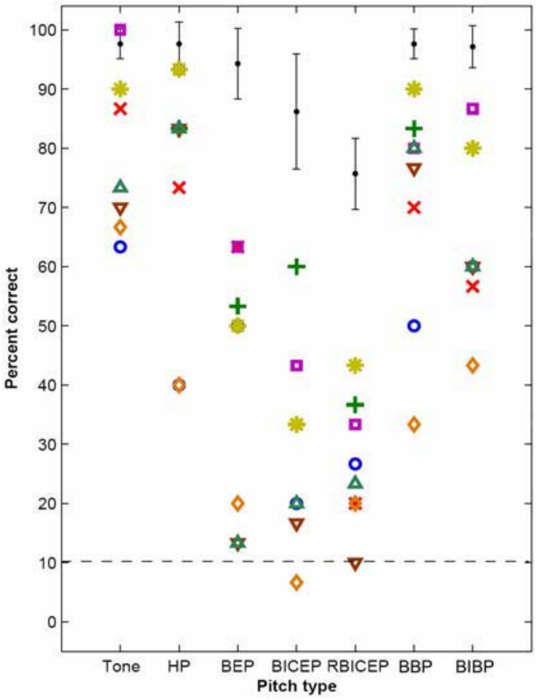

Figure 2: Melody-recognition of pure-tones and six types of binaural pitches for the 8 hearing-impaired listeners who perceived binaural pitch. Black dots: the average results for 14 normal-hearing listeners.

Simulations

The binaural-pitch signals of Fig. 1 were fed through the modified equalization-cancellation (mEC) auditory model [3]. The output of the mEC model shows a peak around *fb* for all pitch types except the binaural coherence edge pitches (BICEP and RBICEP). The model accounts for the fact that HP, BBP, and BIBP are perceived similarly. The width of the auditory filters affects the sharpness of the peak or edge within the model, but not its amplitude. Thus the amplitude alone does not account for the salience of the binaural pitch. No peak, but only an edge, is obtained with the BICEP and RBICEP stimuli, suggesting that a contrast-enhancement mechanism, such as lateral inhibition, might be needed for detection of binaural pitch stimuli [2]. Details about the simulations can be found in [1].

Summary and conclusions

Since no correlation between binaural pitch perception and individual audibility was found, additional tests are essential to better characterize (individual) hearing impairment and to determine which functions of the auditory system are affected. Frequency selectivity proved a very interesting measure: The width of the auditory filters was found to have an important influence on the perception of binaural stimuli, and to explain some differences observed even among normal-hearing listeners. The fact that different hearing-impaired listeners were found to react differently to binaural-pitch stimuli, and that their perception was either immediate or non-existing, makes binaural-pitch stimuli potentially useful for clinical diagnostics. For example, if it was shown that only listeners with central auditory deficiencies were unable to perceive binaural pitch, then a short binaural-pitch

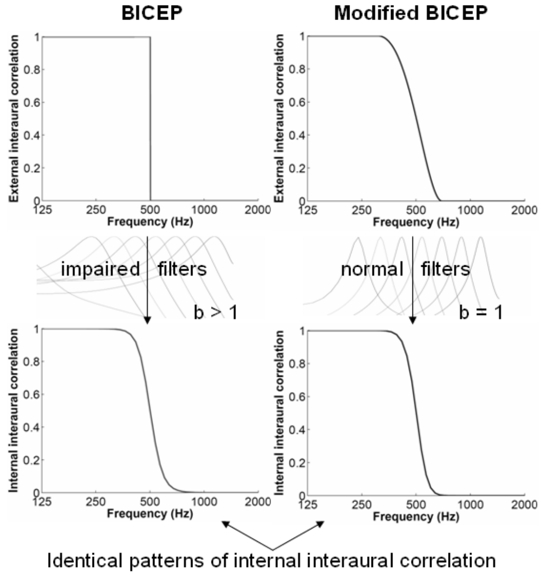

Figure 3: Modification of the BICEP stimulus using a smoothed transition in the interaural correlation in order to simulate broader auditory filters.

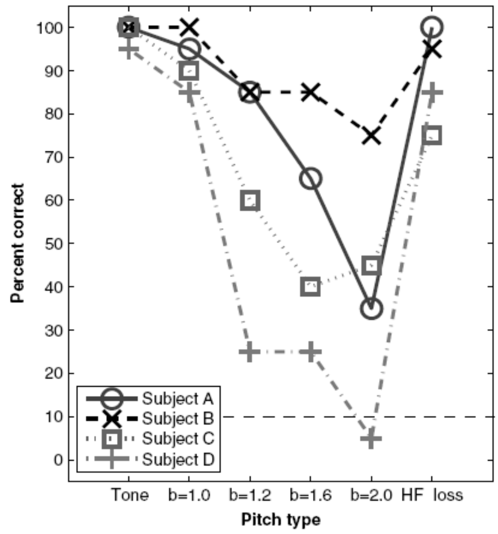

Figure 4: Melody-recognition of pure-tones, BICEP (b=1.0) and four modified versions of the BICEP stimulus (b=1.2, 1.6, 2.0, HF-loss) in four normal-hearing listeners.

detection test could be designed to test deficiencies in the upper stages of the auditory system.

References

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[3] Culling, J.F., Summerfield, A.Q., Marshall, D.H.: Dichotic pitches as illusions of binaural unmasking. J. Acoust. Soc. Am., 1998; 103 (6), 3509-3526.