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Perceptual weighting of elevation localization cues across frequency

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Introduction

Much research has been conducted on the integration of information of binaural lateralization cues over frequency. Macpherson and Middlebrooks (2002) showed that listeners weight interaural time differences (ITDs) more strongly at low than at high frequencies, while interaural level differences (ILD) are weighted more strongly at high frequencies. These findings were coherent with the proposed duplex theory of Lord Rayleigh (1907). Other studies have confirmed that binaural information is integrated over frequencies in the binaural system to lateralize sounds (Buell and Hafter, 1991; Woods and Colburn, 1992) using a spectral weighting function (Ahrens et al., 2015). While these studies investigated the weighting of information over frequency in horizontal plane, no such weighting exists for vertical (elevation) localization.

In this study, we aimed to investigate if certain frequency areas are perceptually weighted higher than others. Furthermore, predictors of perceptual weights in the head-related transfer functions (HRTFs) were investigated.

Methods

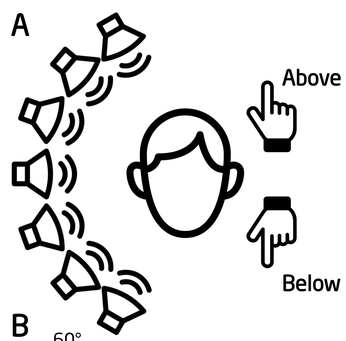
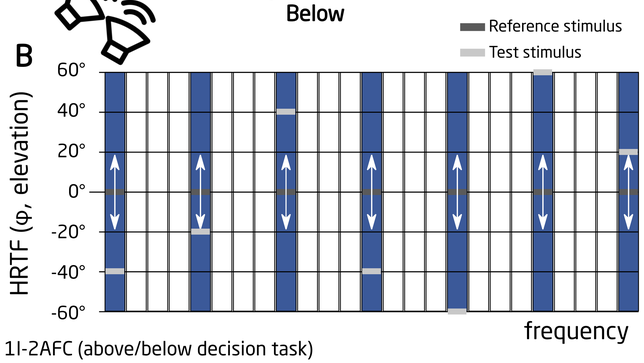


Fig. 1: A) The listeners were instructed to rate if a test stimulus was perceived above/below a reference stimulus. **B)** The test stimulus contained seven 1 ERB wide noise bands with randomly permutated individual HRTFs from seven elevations. The reference stimulus contained the same frequency bands but all with an elevation of φ=0°. An example test stimulus is shown in light grey and the reference stimulus in dark grey.

Each stimulus was 300ms in duration. The procedure was repeated 245 times for each condition.



- 1I-2AFC (above/below decision task)
- 7 **individual** elevation HRTFs (φ=-60°:20°:60°)
- Azimuth angles (θ) at 15° and 45° (left)
- Wide and narrow frequency range (0.95-15.5kHz, 3.2-12.4 kHz)
- Stimuli presented via equalized open headphones (Sony PFR-V1)
- 11 normal-hearing participants

Perceptual elevation weighting

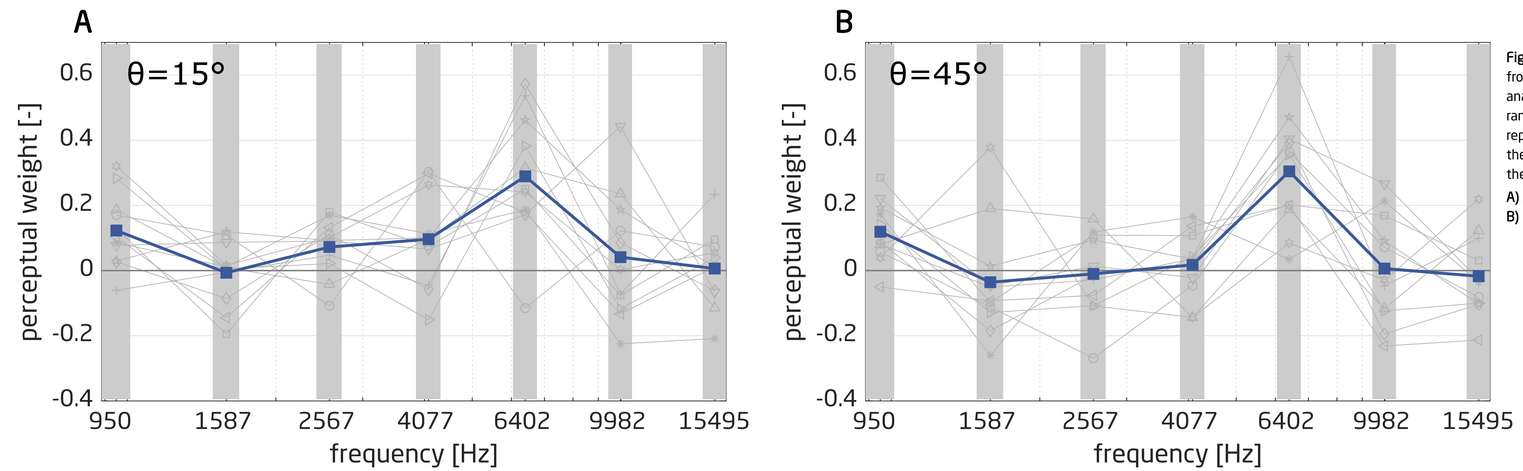


Fig. 2: Perceptual weights calculated from a multinomial regression analysis for the wide frequency range condition. The grey lines represent the individual results from the 11 listeners and the blue line the mean over the listeners.

A) Azimuth angle of 15° to the left.
B) Azimuth angle of 45° to the left.

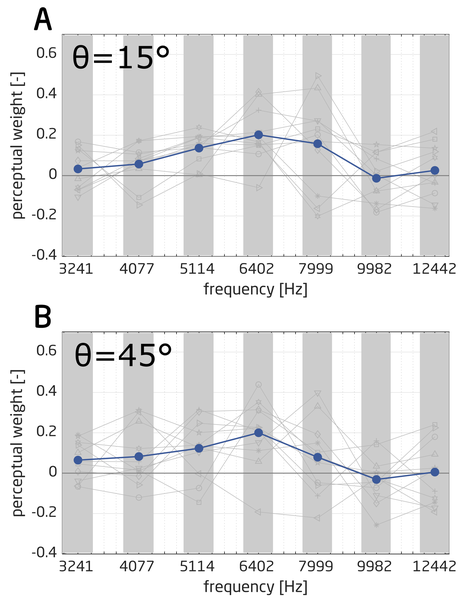


Fig. 3: Perceptual weights calculated from a multinomial regression analysis for the narrow frequency range condition. The grey lines represent the individual results from the 11 listeners and the blue line the mean over the listeners.

A) Azimuth angle of 15° to the left. **B)** Azimuth angle of 45° to the left.

Relation between perception and HRTF features

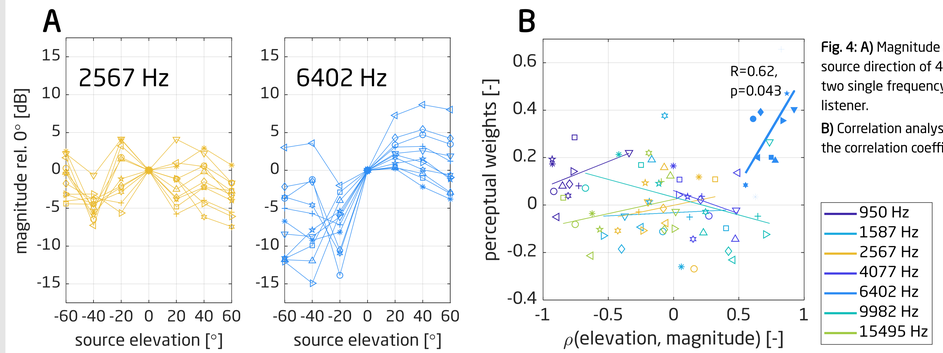


Fig. 4: A) Magnitude at the ipsi-lateral ear for a azimuth source direction of 45° with respect to the source elevation in two single frequency bands. Each symbol represents a listener.

B) Correlation analysis between the perceptual weight and the correlation coefficient of elevation and magnitude.

Discussion & Conclusions

- The frequency band of 6.4 kHz is perceptually weighted largest with respect to elevation, however the intra-subject variation is large
- The magnitude variation predictability over the elevations of the individual HRTFs correlates with the perceptual weights
- A narrow frequency range seems to lead to less reliable perceptual weighting results
- Results are a perceptual extension to directional/boosted bands (Blauert, 1997)
- Step towards a weighting function for computational models (e.g. Zonooz et al., 2019)

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