Data on the detection of infrasound with both ears

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Introduction

Numerous studies have shown that the human ear is able to perceive infrasound (< 20 Hz) if the sound-pressure level of the corresponding signal is high enough (e.g., [1–9]). In some studies, stimuli were presented monaurally, in others binaurally; but – to our knowledge – binaural presentations always involved the whole body, as no suitable sound reproduction system had been available.

In our previous hearing experiments on infrasound perception, a compact low-distortion plug-in earphone system (Low-Distortion Sound Reproduction System, LDREPS) was used, which was designed for monaural reproduction and recording of infrasound in the ear canal. Among others, the influence of infrasound on the perception of amplitude modulations at low frequencies ([6]), phase effects with infrasound within one ear ([7]), and the monaural spectral and temporal integration of infrasound ([8, 9]) were investigated. Monaural conditions are, however, less common in everyday life, as environmental sounds usually reach both ears. Furthermore, it is known from studies using sounds in the classical audible-frequency range that the presentation of acoustic stimuli to both ears can affect the perception of the stimuli compared to the presentation to one ear (e.g., binaural advantages in detection thresholds, binaural beats).

Our aim was to examine binaural effects for infrasound. More specifically, we addressed the following questions:

1. Are infrasound stimuli that reach both ears summed binaurally to yield a binaural threshold?
2. Binaural advantage for infrasound: Are binaural thresholds lower than monaural thresholds at the "better" ear?
3. Do thresholds differ between binaural (diotic) and dichotic infrasound-stimulus conditions when …
    a. the numbers of bursts are equal or
    b. the stimulus durations are equal?

To answer these questions, we measured detection thresholds of multiple-burst infrasound stimuli, which were presented monaurally or binaurally. If not stated otherwise, in the following, binaural stimulation refers to a diotic presentation of the sounds, i.e., the same signal in both ears. In addition, a dichotic stimulus was included in the experiment to investigate if threshold change when sounds are not presented simultaneously in both ears.

Methods

Detection thresholds were measured with an adaptive 3-interval 3-alternative forced-choice procedure with 1-up–2-down rule for three listeners (see Table 2). One listener had a severe hearing loss on the right side. For every condition, the estimator of the threshold was determined as the median of three individual thresholds (in dB).

Table 1: Information on the listeners.

Listener	Sex, age	Hearing levels
L1	female, 26	< 15 dB left and right
L2	male, 41	< 15 dB left and right
L3	male, 34	< 15 dB left, hearing loss right

Five different stimuli were used: MB1, MB2, MB4, S, and E. Stimuli MB1, MB2, and MB4 had envelopes with one, two, or four consecutive bursts (van Hann riseing and falling ramps, no plateaus, 750 ms per burst). They were presented monaurally (only to one ear at a time) or binaurally (i.e. diotically, i.e., to both ears simultaneously). Stimuli S and E were similar to MB2 but started (S) or ended (E) with a silent gap and had another gap between the bursts (750 ms per gap). They were presented binaurally (diotically, i.e., only S or only E to both ears) or dichotically (i.e., S to one and E to the other ear).

All stimuli had a carrier frequency of 8 Hz. They were presented with a binaural LDREPS (Low-Distortion Sound-Reproduction System). Key parts of the LDREPS are the audiometric earphone transducers RadioEar DD45 mounted in an air-sealed aluminum housing with a sound outlet in the front plate. A sound tube connects the sound outlet to the ear insert of an Etymotic ER-10B+ low-noise microphone system. The properties of a monaural version of the LDREPS have been described in [10]. To ensure the proper fit of the ear inserts, the sound-pressure level of a 4-Hz signal, which had been calibrated in a B&K 4157 occluded-ear simulator (Brüel & Kjær, Nærum, Denmark), was always measured in situ by means of the in-built low-noise microphones of the LDREPS prior to the next experimental condition.

Results and Discussion

Figure 2 shows the results for the MB1, MB2, and MB3 stimuli. The left column shows the sound-pressure levels at threshold when stimuli were presented to the right ear only (R, red), to the left ear only (L, blue), or to both ears simultaneously (B for binaural, yellow). The right column shows the level differences between the binaural threshold and the right-ear (R-B, red) or the left-ear (L-B, blue) threshold. Since the binaural advantage is defined as the level difference for the "better" ear, the blue curves are also the binaural advantages for the three listeners in this study.

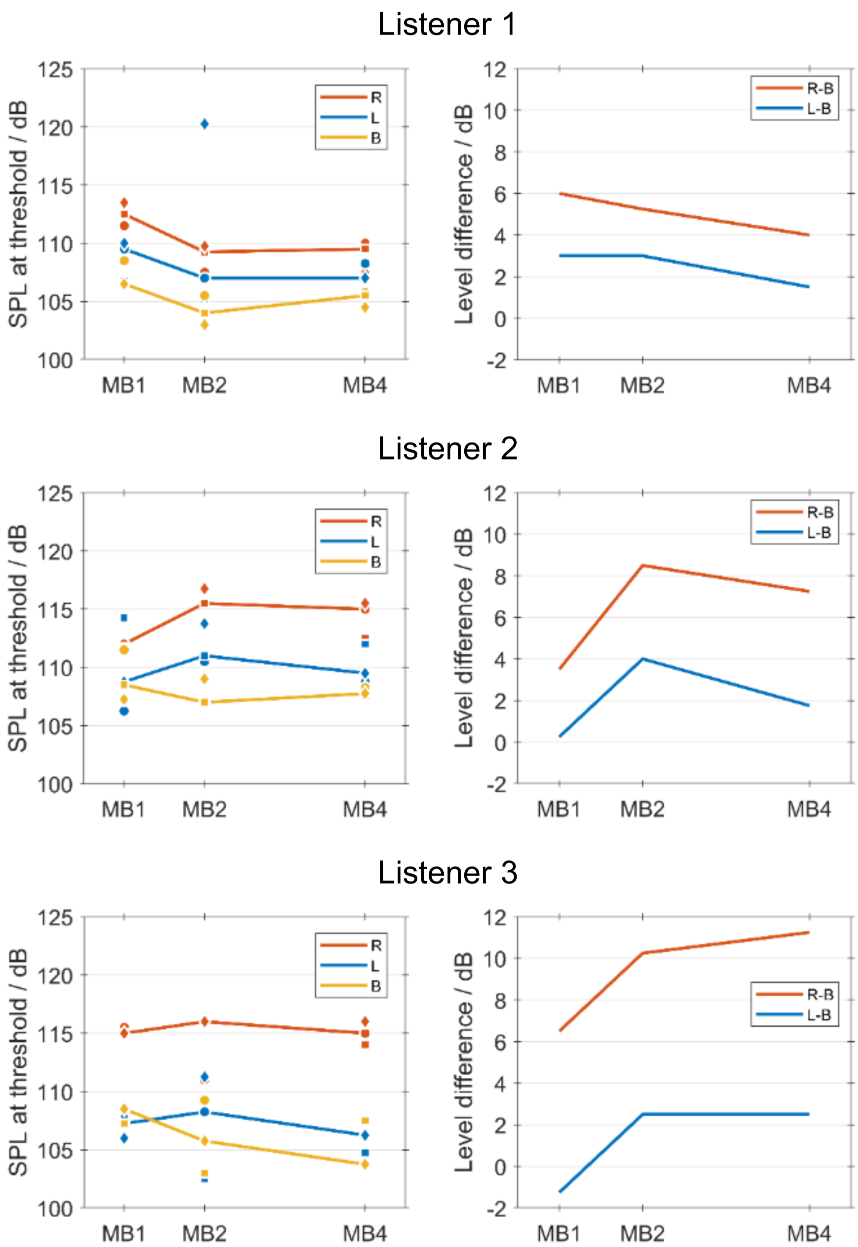

Figure 1: The left column shows the sound-pressure levels at threshold of the MB1, MB2, MB4 stimuli that were presented to the right ear (R, red), to the left ear (L, blue), or to both ears simultaneously (B, yellow). Symbols denote the three individual thresholds per stimulus. Lines go through the medians of the three individual thresholds. The right column shows the level differences between the binaural threshold and the right-ear (R-B, red) or the left-ear (L-B, blue) threshold.

For Listener 1, the threshold–duration curves (left column) appear about as expected for temporal integration, i.e., threshold decrease as the number of bursts increases. The curve for the right ear is about 3 dB above that for the left ear, meaning that the latter was the better ear. The curve for the binaural condition is below that of the left ear. The level difference (right column), and therefore the binaural advantage, is about 1.5 dB (MB4) to 3 dB (MB1 and MB2).

For Listener 2, the threshold–duration curves (left column) for the monaural conditions strongly increase between MB1 and MB2, which is unexpected from average temporal integration but which we observed in some listeners of previous studies. The left ear was by 5 dB to 6 dB better than the right ear. With the exception of MB1, there was a binaural advantage (right column) of up to 4 dB.

For Listener 3, the threshold–duration curves (left column) for the monaural conditions increase between MB1 and MB2, again unexpectedly from average temporal integration data. Note that Listener 3 has a severe hearing loss on the right side as confirmed by standard audiometry (no thresholds determinable for frequencies ≥ 1 kHz). At the lowest audiometric frequency (125 Hz), the audiogram revealed a left–right difference of about 10 dB. The present 8 Hz data show that the left ear was by 7 dB to 8 dB better than the right ear. With the exception of MB1, there was a binaural advantage (right column) of 2.5 dB.

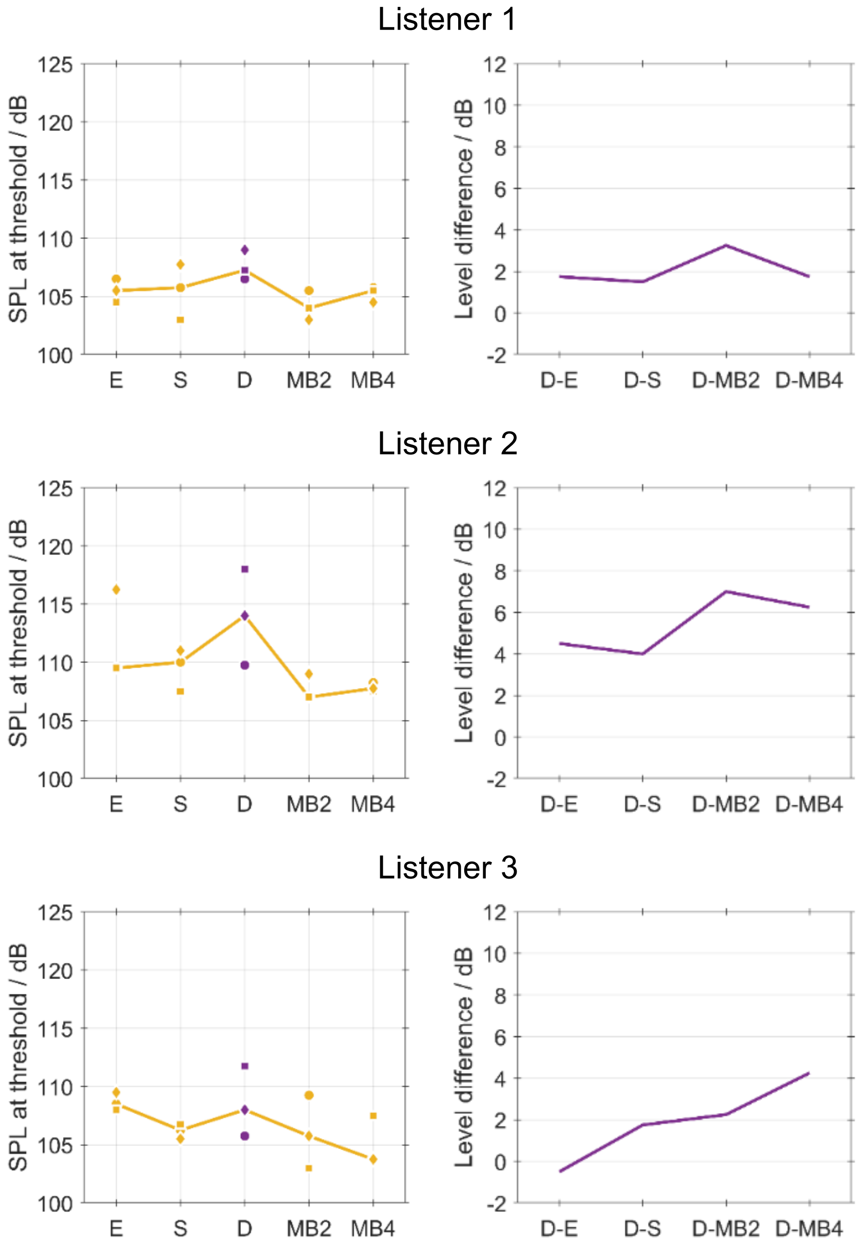

Figure 2: The left column shows the sound-pressure levels at threshold of the E and S stimuli presented binaurally (E and S, yellow) or dichoticly (D, purple). In addition, the binaural thresholds of MB2 and MB4 are reproduced from Figure 2. Symbols denote the three individual thresholds per condition. Lines go through the medians of the three individual thresholds. The right column shows the level differences between the binaural thresholds and the dichotic threshold. When a level difference is positive, this can be interpreted as an advantage of the corresponding binaural stimulus over the dichotic stimulus.

Figure 3 shows the data of the stimuli with silent gaps. The left column shows the sound-pressure levels at threshold of the binaural (diotic, yellow, E and S) and dichotic (D, purple) conditions. In addition, the binaural conditions for MB2 and MB4 were reproduced from Figure 2 for comparison. The right column shows the level differences between the binaural thresholds and the dichotic threshold.

For Listener 1, the dichotic threshold was highest (left column). This is reflected also by the level differences (right column), which are all positive. Most binaural thresholds were by about 2 dB lower than the dichotic threshold, MB2 was even 3.5 dB lower.

For Listener 2, the dichotic threshold was also highest (left column). Note, however, that individual thresholds of stimuli with silent gaps varied up to 8 dB. Level differences (right column) varied between 4 dB and 7 dB reflecting a relatively strong advantage of the binaural stimuli over the dichotic stimulus.

Also for Listener 3 with severe hearing loss on the right side, the dichotic threshold was high; but it was slightly exceeded by the threshold of E. The threshold difference between E and S was about 3 dB with low variability in individual thresholds. This was rather unexpected, as S and E differ only in that one starts and the other end with a silent gap while all other stimulus properties are equal. In fact, the model of temporal integration [9] would predict their thresholds to be the same. The level differences between the binaural thresholds and the dichotic threshold (right column) varied between 2 dB and 4 dB, except for the difference to E (–0.5 dB).

Summary and Prospects

In this paper it was investigated, whether infrasound stimuli that reach both ears are summed binaurally to yield a binaural threshold. The data suggest that this is the case and that, for multiple-burst stimuli without silent gaps, there is a binaural advantage of up to 4 dB. It was also investigated how thresholds differ between binaural (diotic) and dichotic conditions with multiple-burst infrasound stimuli with silent gaps at different locations. It was found that dichotic thresholds were generally highest. However, threshold differences varied greatly. More data are required to allow for performing proper statistical analyses and modeling the data.

Acknowledgments

We would like to thank the German Research Foundation for funding our project “Binaural Infrasound Perception” (VE 373). We would also like to thank Holger Joost from the Physikalisch-Technische Bundesanstalt for his support in setting up the binaural LDREPS and Martin Gottschalk for his assistance with the calibration.

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