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DOES A FREQUENCY MISMATCH BETWEEN INFRASOUND AND MODULATOR AFFECT THEIR INTERACTION?

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ABSTRACT

In a previous study, we showed that a supra-threshold, sinusoidal infrasound stimulus (8 Hz) not only masks a low-frequency sound in the audio-frequency range (64 Hz) but also influences the perception of an 8 Hz temporal amplitude modulation (AM) imposed on the 64 Hz carrier (cf. Friedrich, Joost, Fedtke, Verhey, 2023, Acta Acustica 7, https://doi.org/10.1051/aacus/2023061). In an additional study, we showed that AM thresholds for 8 Hz depend on the relative phase between infrasound and AM. On average across the listeners of that study, the maximum AM threshold was close to 270°, the minimum close to 90°. The threshold difference between the extrema was 10 dB. In this study, we investigated how thresholds change with modulation frequency, i.e., by including conditions, where infrasound frequency and modulation frequency are not the same.

Keywords: *infrasound, low-frequency sound, masking, amplitude modulation, absolute threshold*

1. INTRODUCTION

Several studies showed that the human auditory system can perceive infrasound, i.e., sound with frequencies below 20 Hz, provided that the sound pressure level (SPL) of the corresponding signal is high enough (e.g., [1–12]). The exact mechanisms of auditory infrasound perception are still not fully understood. One hypothesis is that the infrasound interacts with other sound components in the audio-frequency range, i.e., the range from 20 Hz to 20 kHz.

One type of interaction is masking, i.e., the increase of the detection threshold of one stimulus by the presence of another stimulus, here referred to as the masker. Using infrasound sinusoids, Burke et al. [6] found that the presence of a 100 Hz pure-tone masker at a sensation level (SL) of 50 dB caused a significant increase in the detection threshold at 12 Hz by 10 dB. At 5 Hz, the increase was 3 dB, but it did not reach significance. They also tested the effect of sinusoidal infrasound maskers on the detection of audio-frequency stimuli. Using a 12 Hz masker at an SL of 10 dB, they measured a small amount of masking at a target frequency of 100 Hz, but, again, it was not significant. In a previous study [10], we showed that an 8sinusoid at an SL of 9 dB masked a pure tone with a low frequency of 64 Hz by 4.5 dB.

Another type of interaction might occur at the level of AM perception. Marquardt and Jurado [4] reported that human listeners had difficulties distinguishing a 63 Hz carrier modulated at 8 Hz from a 63 Hz pure tone in the presence of a supra-threshold 8 Hz infrasound sinusoid. This supports the hypothesis that infrasound may be perceived as AM. In a previous study [10], we showed that an 8 Hz sinusoid at an SL of 9 dB influences the perception of an 8 Hz temporal AM imposed on the 64 Hz carrier, the SL of which was set to 25 dB. The presence of the masker led to an increase in modulation detection threshold of up to 4 dB. In an additional study with similar stimuli [12], we focused on the phase position between the infrasound masker and the modulator. The dependence of the AM threshold on the phase position had an approximately sinusoidal curve. The phase effects between 0° and 180° were individually different. The individual AM thresholds for these phases were almost similar to those determined in the previous study [10]. The maximum AM threshold was close to 270°,

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the minimum close to 90°. The threshold difference between these extrema was 12 dB and comparable to the effects measured in the auditory-frequency range (e.g., 10 dB in [13]).
In this study, we investigated how modulation detection thresholds change with modulation frequency, i.e., by including conditions, where masker frequency and modulation frequency are not the same.

2. METHODS

The study comprised two experiments on detection thresholds of sinusoidal signals (detection experiments) and two experiments on thresholds for detection of a sinusoidal amplitude modulation imposed on a sinusoidal carrier (modulation detection experiments). Thresholds were measured for one listener by means of an adaptive 3-interval 3-alternative forced-choice procedure with 1-up–2-down rule. For every condition, the estimator of the threshold was determined as the median of three individual thresholds (in dB).
Detection thresholds were measured for sinusoids with a frequency of 8 Hz (infrasound, experiment 1) and 64 Hz (low-frequency sound, experiment 2) in quiet. In addition, in experiment 2, the threshold of the 64 Hz sinusoid was measured in the presence of an 8 Hz masker. The SL of the masker was set to 9 dB above the listeners' individual 8 Hz threshold that was determined in experiment 1. The starting phase of the masker was chosen randomly from a uniform distribution between 0 and 360° in each trial.
In the modulation detection experiments, sinusoidal AM at frequencies f_M of 5 Hz, 6 Hz, 8 were imposed on a sinusoidal carrier with a frequency f_C of 64 Hz using the following equation:

$$s(t) = A \cdot \sin(2\pi f_C t) \cdot (1 + m \cdot \sin(2\pi f_M t)) \qquad (1)$$

where A is the amplitude of the carrier and m the modulation index. Modulation detection thresholds were determined in terms of the modulation depth, expressed as $20 \cdot \log10(m)$ dB. The carrier level, determining A in Eqn. (1), was set to 24 dB above the listeners' individual threshold for that frequency, i.e., to an SL of 24 dB. In experiment 3, the modulation detection threshold was determined in the absence of any other sound, serving as a reference (Ref) threshold. In experiment 4, modulation-detection thresholds were determined in the presence of the same 8 Hz masker that was used in experiment 2 (see above). Again, the starting phase of the masker was chosen randomly from a uniform distribution between 0° and 180° in each trial.
All signals used in the experiments had a duration of 1500 ms, including van-Hann ramps at the beginning and the end of the stimulus. Each ramp was 250 ms long, which corresponds to two cycles of 8 Hz. Stimuli 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 [5]. 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.

3. RESULTS AND DISCUSSION

Fig. 1 shows the detection thresholds at 8 Hz and 64 Hz in quiet (blue bars) and at 64 Hz in the presence of the 8 Hz masker at an SL of 9 dB (orange bar) for the listener considered in this work. Colored bars represent the medians across three individual sound-pressure levels at threshold per condition and black error bars the interquartile ranges. The median threshold at 8 Hz is 106.5 dB and compatible with average monaural thresholds reported in the literature [10]. The median thresholds at 64 Hz are 35 dB and 36.5 dB, which is lower than average monaural thresholds reported in the literature (e.g., 45.5 dB and 50 dB in [10]). The effect of masking, quantified as the difference between the detection threshold in the presence and in the absence of the masker, was also lower (1.5 dB versus 4.5 dB)

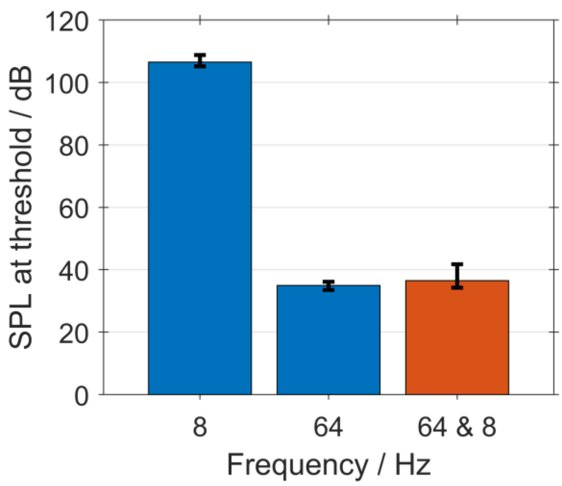

Figure 1. Detection thresholds at 8 Hz and 64 Hz in quiet (blue bars) and at 64 Hz in the presence of the 8 Hz masker at an SL of 9 dB (orange bar) for the listener considered in this work. Colored bars represent the medians across three individual sound-pressure levels at threshold per condition and black error bars the interquartile ranges.

Fig. 2 shows the modulation thresholds as a function of the modulation frequency in the absence (blue diamonds) and in the presence (orange squares) of the 8 Hz masker at an SL of 9 dB. Symbols represent the medians across three individual modulation depths at threshold per condition. Modulation thresholds vary between -12.5 dB and -17 dB and are highest at 6 Hz and 11 Hz. Values at 8 Hz (-16.75 dB to -13.25 dB) are comparable to average monaural values reported in the literature (e.g., -11 dB in [10]).

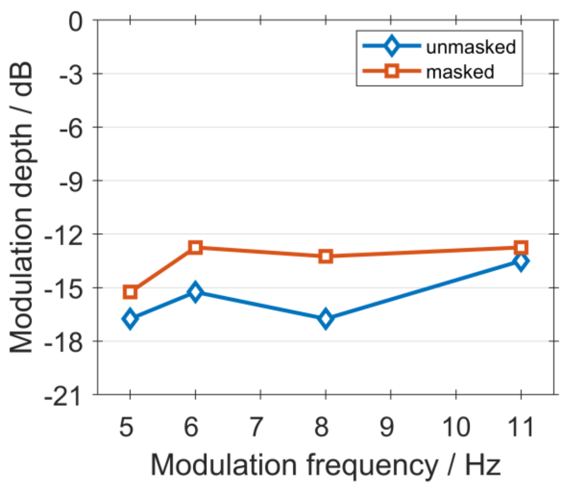

Figure 2. Modulation thresholds as a function of the modulation frequency in the absence (blue diamonds) and in the presence (orange squares) of the 8 Hz masker at an SL of 9 dB. Symbols represent the medians across three individual modulation depths at threshold per condition.

Fig. 3 shows the masking as a function of the modulation frequency. The effect is quantified as the difference in the median modulation thresholds between masked and unmasked conditions (see Fig. 2). Masking increased from 5 Hz (1.5 dB) to 8 Hz (3.5 dB) and then decreased to 11 Hz (0.75 dB). This is compatible with the idea that the effect of masking on modulation detection is the larger the closer the modulation frequency is to the masker frequency. Note that the relative phase between modulator and masker had been chosen randomly in every trial. Still, the masking at a modulation frequency of 8 Hz was about the same as the average masking values for fixed phase relations of 0° and 180° reported in the literature (e.g., between 3 dB and 4 dB in [10]).

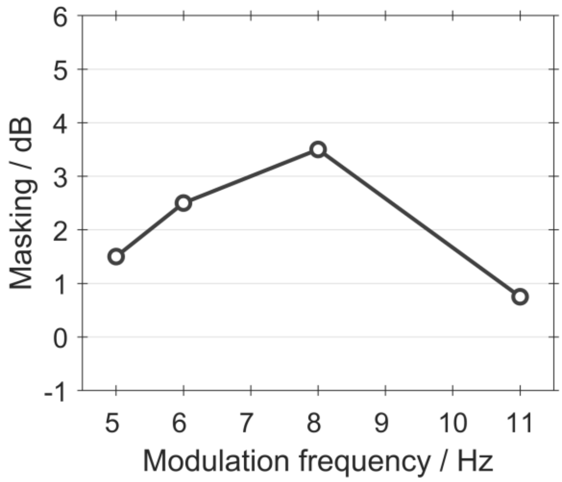

Figure 3. Masking as a function of the modulation frequency. The effect is quantified as the difference in the median modulation thresholds between masked and unmasked conditions (see Fig. 2).

4. SUMMARY

In this paper, it was investigated how modulation threshold of a low-frequency carrier changes with modulation frequency in the infrasound range. The change was measured in the absence and in the presence of a supra-threshold infrasound masker. Data from one listener suggest that 8 Hz masks the detection threshold at 64 Hz as well as the modulation thresholds for 64 Hz at all modulation frequencies from 5 Hz to 11 Hz. Masking was largest at a modulation frequency of 8 Hz, i.e., when modulation frequency and masker frequency were equal. More data are required to allow for performing proper statistical analyses.

5. ACKNOWLEDGMENTS

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