

Rumbling and humming as a function of loudness level

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Introduction

Low frequencies are frequencies in the audible range below a maximum frequency (80 Hz to 250 Hz, depending on which definition is used). Tonal low-frequency sound is often emitted by technical devices like, e.g., heat pumps or vehicles. Specific sensations for low-frequency tonal sounds have been proposed, such as “rumbling”, “humming” and “booming”. They have been used to characterise, e.g., vehicle interior sounds [1]. The present study focusses on the sensations of humming and rumbling. Humming is commonly associated with the perception of low-frequency unmodulated tones, whereas rumbling is associated with temporal amplitude modulation (AM) of low-frequency carriers. A listening test with artificial sounds - unmodulated and amplitude-modulated - was conducted, using a broad range of signal parameters. The sounds were rated on a categorical scale.

Methods

Subjects

Eight subjects were invited to the experiment. They reported no hearing loss or tinnitus. Absolute hearing thresholds were ≤ 15 dB hearing level (HL) for all audiometric frequencies below 2 kHz.

Apparatus

Sounds were presented via Sennheiser HDA 280 headphones monaurally on the left ear for most subjects, and on the right ear for one subject. The headphones were calibrated using a Brüel & Kjær type 4153 artificial ear. Simultaneously, the frequency-specific sensitivity of a small electret condenser microphone positioned under the earcup of the headphone was measured. This microphone was also worn under the earcups by subjects during the experiment. It was used for in-situ corrections of sound pressure level, since suboptimal headphone fitting can lead to leakage, especially for very low frequencies¹. Corrections of up to ± 5 dB were allowed. If this was not sufficient, subjects were asked to adjust the headband length for a better fit and/or take off glasses, in case they were wearing them.

Signals

Waveforms were calculated digitally using the following formula:

$$p(t) = p_0 \cdot 10^{\frac{L_{\text{ELLC}}}{20\text{dB}}} \cdot \sin(2\pi ft) \cdot (1 - m \cdot \cos(2\pi f_{\text{mod}}t))$$

The levels for L_{ELLC} (Level of Equal-loudness level con-

¹We thank Manfred Zollner and Roland Sottek for their advice regarding this issue at DAGA 2024

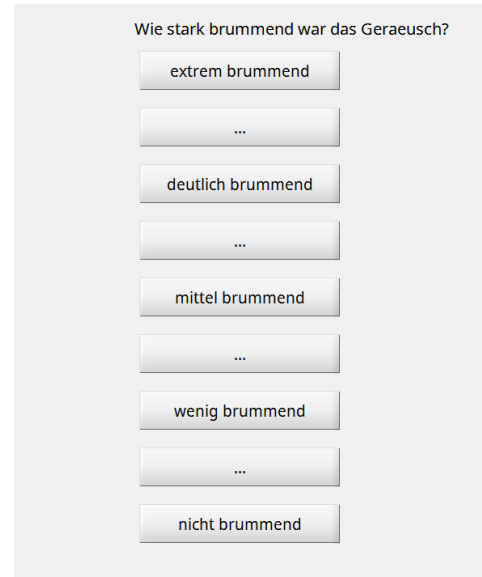


Figure 1: Graphical user interface with categorical scale, shown here for humming (“Brummen“)

tour) were chosen for each loudness level according to the ISO standard 226 [2]. The following parameters and all of their combinations were used in the experiment:

Carrier frequency f :	[20, 40, 80, 160, 315] Hz
Modulation rate f_{mod} :	[2, 4, 8] Hz
Loudness level L_N :	[30, 40, 50] phon
Modulation depth m :	[0, 100] %

On signal onset and offset, each signal had raised-cosine ramps with a length of 4 periods of the respective carrier frequency.

Introduction phase

Before the beginning of the experiment, prototypical sounds were presented for 10 s for each sensation. For humming, a tone with a frequency of 50 Hz was used. The level was faded in and out. For rumbling, an AM tone with a carrier frequency of 40 Hz and a modulation rate of 8 Hz was used. The modulation depth was faded from 0 to 1 and back to 0. The same sounds have been used by [3]. Subjects were instructed to listen to the change of the sound during the fade in and fade out and associate that with a changing strength of humming and rumbling, respectively.

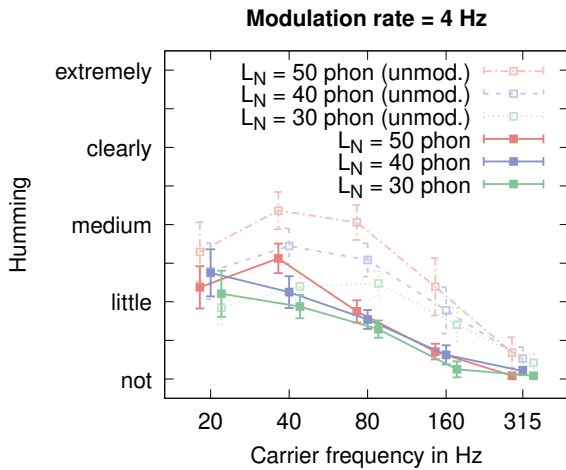


Figure 2: Average humming ratings over all subjects. Ratings of unmodulated tones in faint colors, ratings of modulated sounds with a modulation rate of 4 Hz in opaque colors. Error bars indicate plus and minus one standard error of the mean.

Procedure

The sounds of all 90 possible parameter combinations were presented in a random order. For each sound, subjects were asked to rate their sensation of humming or rumbling on a categorical scale (as shown in Fig. 1). The question for humming was “Wie stark brummend war das Geräusch?“ (“What was the strength of humming of the sound?“). The scale consisted of the named categories “nicht brummend” (not humming), “wenig brummend” (little humming), “mittel brummend” (medium humming), “deutlich brummend” (clearly humming), and “extrem brummend” (extremely humming) as well as four unnamed categories in between. Analogous categories were used for the sensation of rumbling. For each sensation, the full set of sounds was presented three times. The experiment was approved by the ethical committee of the medical faculty of the Otto von Guericke University Magdeburg (approval number 107/22).

Results

The results of the categorical ratings are shown in Fig. 2 and Fig. 3, respectively. Only the results for unmodulated sounds and the modulation rate of 4 Hz are shown. None of the unmodulated 315 Hz tones elicited the sensation of humming. Humming increased for the unmodulated sounds as the frequency decreased from 315 Hz to 40 Hz for the two higher levels and down to 80 Hz for the lowest level.

In general, humming increased with loudness level and was smaller for modulated sounds. Modulation decreased humming more for the medium carrier frequencies 40 Hz and 80 Hz. For the two lower loudness levels, a maximum at 40 Hz to 80 Hz was no longer observed.

Rumbling occurred mainly for carrier frequencies < 80 Hz, the strongest rumbling was found for 20 Hz. Note that the subjects rated none of the sounds as extreme with respect to the sensations of humming and rumbling. This

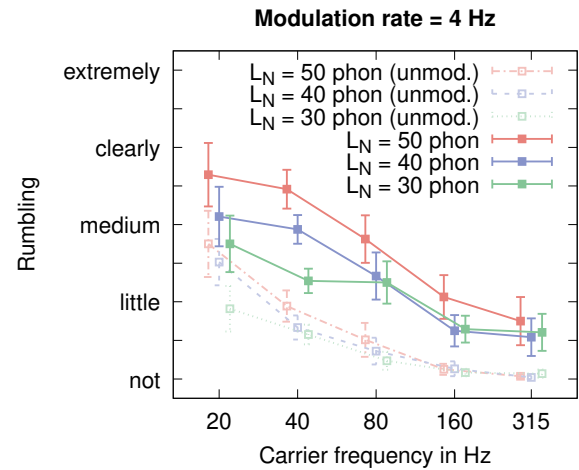


Figure 3: Average rumbling ratings over all subjects. Ratings of unmodulated tones in faint colors, ratings of modulated sounds with a modulation rate of 4 Hz in opaque colors. Error bars indicate plus and minus one standard error of the mean.

may be partly due to the levels that were used in the experiment. A loudness level of 50 phons for a 1 kHz tone has an average loudness on a categorical scale between soft and medium loud [4].

In general, rumbling increased with loudness level, especially when modulated. Rumbling increased with modulation depth, in contrast to the results for humming.

Conclusion

Low-frequency tonal sounds elicit specific sensations. We investigated the influence of signal parameters on humming and rumbling. Both sensations increased with loudness level. Whereas humming decreased with modulation, rumbling increased with modulation. A sensation of rumbling was elicited even without modulation for low (carrier) frequencies.

Acknowledgment

We thank Deutsche Forschungsgemeinschaft for supporting this work (DFG Project 517759354).

References

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