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An experimental study on the perception of infrasound – Do we need the infrasound term at all?

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ABSTRACT

The aim of this study was to experimentally determine the hearing threshold level, annoyance at specified loudness levels, and other sensations apart from hearing for tones within 4–8000 Hz. Nineteen normal-hearing people participated in the laboratory experiment. The hearing threshold level agreed with previous studies, which proposes that the playback and measurement systems were appropriate. Annoyance was studied at 20, 40, and 60 phon loudness levels. The annoyance of infrasonic frequencies did not basically differ from the annoyance of non-infrasonic frequencies. Opposite, the annoyance of 2–8 kHz was higher than the annoyance of infrasonic tones. The annoyance vs. level slopes emphasized the non-linear nature of hearing: the slopes became drastically steeper with decreasing frequency. That is, the dynamic range of hearing suppresses towards lower frequencies. Because individual hearing thresholds varied up to 20 dB, an infrasonic tone still being inaudible for one participant could be annoying for another participant. The finding may explain why some people perceive low frequency sound more annoying than the others. Other sensations apart from hearing (e.g., pressure in the ear, headache) were reported both for tones of infrasonic and non-infrasonic frequencies. This suggests that infrasonic and non-infrasonic frequencies share similar phenomena. Therefore, the need of term "infrasound" can be questioned since it is misleading. Although the behavior of hearing becomes different towards lower frequencies, there is no justification to draw a division line at 20 Hz.

Keywords: Infrasound, annoyance, hearing threshold level, perception, hearing

INTRODUCTION

Infrasound is usually defined as sound which has frequency under 20 Hz or 16 Hz. It is also frequently specified that those frequencies are below the hearing range. It is surprisingly often stated, both in scientific and in non-scientific contexts, that infrasound is inaudible. One important reason to this may be that the hearing threshold level is only standardized within

20–16000 Hz (ISO, 226).

There are many scientific studies which have shown that short-term whole-body infrasound exposure has adverse effects on human (see review of ACGIH, 2001). Research on intense infrasound was conducted especially in 1960's when manned space flights became popular and the exposure to infrasound was topical. However, adverse effects occurred only when the sound pressure level (SPL) exceeded 140–150 dB. Therefore, it is not the presence of infrasound that causes adverse effects *per se* – it is the SPL of infrasound that matters.

However, target values for infrasound exist in very few countries. As usually, different target values should be applied for work and residential environments. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends that, except for impulsive sound with durations of less than 2 seconds, SPLs at one-third octave bands between 1 and 80 Hz should not exceed the SPL ceiling limit of 145 dB, and the overall unweighted SPL should not exceed the SPL ceiling limit of 150 dB (ACGIH, 2001). However, measurement time is not specified. NASA (1995) criteria for noise exposure in space craft and space stations state that SPL shall be less than 120 dB in the frequency range of 1 to 16 Hz for 24-hour exposure. Vercammen (2007) reviewed some national recommendations for infrasound SPL concerning residential apartments. They are mostly defined 5–20 dB below the hearing threshold level of infrasound.

Because of a misconception between the existence and the SPL of infrasound, many people become concerned about the adverse effects of infrasound, if infrasound exists at their living environment and the source for that can be subjectively or objectively addressed. If statutory national target values do not exist, both operators and authorities are unable to assess the potential of adverse health effects. This leads to strange situations where the complainer or physician can make their own subjective conclusions.

Concerns about the adverse health effects of infrasound issue raised in Finland around 2012, when number of industrial wind turbines increased in several areas. The concerns exploded in 2016 when a Finnish party member publicly warned about the possible adverse health effects that new wind turbines would cause for even 650.000 Finnish citizen living nearby planned wind farms. This raised a need for national investigation regarding the perception of infrasound since the basic knowledge about infrasound was insufficient and the authorities could not respond to the claims addressed to infrasound.

The aim of this study was to experimentally determine the hearing threshold level, annoyance at 20, 40, and 60 phon loudness levels, and other sensations apart from hearing for tones within 4–8000 Hz. The full version of the study is given in Rajala et al. (2022).

MATERIALS AND METHODS

Participants. Nineteen participants were recruited through Turku University of Applied Sciences (TUAS) mailing lists. The requirements for participants were: age within 19 – 26 y, native Finnish language, and ability to conduct the experiment without using eyeglasses (to avoid headphones' muff leaks). The research was supported by the TUAS' ethics committee.

Laboratory. The experiment was conducted in a pressure chamber (infrasound booth, Fig. 1), which was located inside an anechoic chamber. The chamber was equipped with two ducts, which acted as reflex tubes making the pressure chamber to behave as a Helmholz resonator. To avoid the escape of sound at and above 4 Hz via the ducts, the resonator was tuned to 1 Hz. One of the ducts involved a ventilation fan. Frequencies 4–63 Hz were produced by four loudspeakers attached to the booth, and frequencies 125–8000 Hz were played using headphones (Sennheiser HDA 300). The participant wore headphones throughout the experiment. Therefore, the SPLs of frequencies within 4–63 Hz were elevated by the amount of the (almost negligible) attenuation of the headphone muffs. The muffs of the headphones attenuated SPL of the ventilation fan much below the mean hearing threshold level (HTL).

Fig. 1. Infrasound booth used in the experiment. Layout and section drawings and a photograph of the booth taken in the anechoic chamber.

Experimental procedure. The experiment involved the following 12 phases (duration in minutes): 1. Information consent form (5), 2. Loudness rehearsal (10), 3. Loudness test part 1 (30), 4. Break (5), 5. Loudness test part 2 (30), 6. Break (5), 7. Hearing threshold test (30), 8. Break (5), 9. Annoyance rehearsal (5), 10. Annoyance test and reporting of any other sensations apart from hearing (17), 11. Verbal description of other sensations apart from hearing (0–20), 12. Gift token. In Phase 11, only those tones were presented to the participant that she/he had reported in Phase 10 to produce any other sensations apart from hearing. That is, the number of tones as well as the duration of the Phase 11 depended on participant. The output was given verbally and spontaneously without a proposed list of sensations. The total duration of the experiment was, on average, 2.5 hours. In this paper, the focus is given on Phases 7, 10, and 11. Phases 3 and 5 yielded equal-loudness contours within 4–1000 Hz. Since the contours agreed reasonably well with previous studies (Møller & Pedersen, 2004), they are not shown.

Hearing threshold level (HTL). The HTL was determined in Phase 7 by applying the ascending staircase method of ISO 8253-1 standard (ISO, 2010). The playback time of each tone was 5 seconds, and the accuracy was 2 dB (step size). The participant was instructed to report a hearing sensation by pressing a button on the screen using mouse. The HTL was the lowest SPL for which the participant reported hearing sensation twice. The basic HTL test was conducted to assure that both playback and measurement functioned properly.

Annoyance. The studied 60 sounds are listed in Table 1. Noise annoyance was measured by question: "*How much does the sound bother, disturb, or annoy you*?" The 11-step response scale was from 0 as "Not at all" to 10 "Extremely annoying". The participants were instructed to use the full scale and try to make their responses as consistent as possible. If the participant felt other sensations apart from hearing sensation, they could express it by selecting a button labeled "I have also other sensations apart from hearing sensation." The verbal description of the sensation was asked in Phase 11. The participants had to listen the sound for 5 seconds before the response scale became visible.

Other sensations apart from hearing. Detailed verbal information about participants' other sensations apart from hearing was inquired, if they reported any existence of other sensations in phase 10. The phase 11 was customized according to individual responses in phase 10: we presented only those individual sounds and loudness levels, for which the participants reported other sensations. The sounds were played once and in the same order as they occurred in the annoyance test. The participants had to listen the sound for 5 seconds before responding became available. The participant described freely in an open form the other sensations that were associated with the sound. The participant could also select one of the buttons “I hear sound, but it is not associated with other sensations apart from hearing.”

Table 1. The SPLs of the equal loudness contours for the 20 studied tones of the annoyance test. The SPLs within 4–16 Hz and 20–8000 Hz are based on Møller & Pedersen (2004) and ISO 226, respectively.

f [Hz]	20 phon [dB]	40 phon [dB]	60 phon [dB]
4	120.7	124.8	127.4
5	118	122	126
6.3	115	120	125
8	109.4	114.3	118.1
10	107	112	116
12.5	103	108	115
16	95.1	101.3	106.9
20	89.6	99.9	109.5
25	82.7	93.9	104.2
31.5	76	88.2	99.1

f [Hz]	20 phon [dB]	40 phon [dB]	60 phon [dB]
63	58.6	73.1	85.9
125	43.9	60.6	75.6
250	32	50.4	67.5
500	23.4	43.1	62.1
1000	20	40	60
1500	21.4	42.5	63.2
2000	18.2	39.2	60
3000	14.3	35.6	56.4
4000	15.1	36.6	57.6
8000	31.5	51.8	71.7

RESULTS

The HTL obtained in Phase 7 is shown in Fig. 2. The annoyance of tones obtained in Phase 10 is shown in Fig. 3. The slopes of the annoyance vs. level curves of Fig. 3 are shown in Fig. 4. The probability of other sensations apart from hearing reported in Phase 10 is shown in Fig. 5. The summary of the types of other sensations apart from hearing reported in Phase 11 is given in Table 2.

DISCUSSION

The HTL agreed with previous review paper (Møller & Pedersen, 2004), which proposes that the playback and measurement systems were appropriate and the forthcoming findings on annoyance are reasonable.

The annoyance of tones of infrasonic frequencies did not basically differ from the annoyance of tones of non-infrasonic frequencies. Opposite to our expectations, the annoyance of 2–8 kHz tones was higher than the annoyance of infrasonic tones. This agrees with Oliva et al. (2017), who found that the annoyance of tonal sound increased with increasing frequency of tone.

The annoyance vs. level slopes emphasized the non-linear nature of hearing: the slopes became drastically steeper with decreasing frequency. That is, the dynamic range of hearing suppresses towards lower frequencies.

Because individual HLTs varied up to 20 dB, an infrasonic tone still being inaudible for one participant could be annoying for another participant. The finding may explain why some people perceive low frequency sound more annoying than the others. However, the HTL variation among population is probably larger than in this experiment.

Other sensations apart from hearing were reported both for tones of infrasonic and non-infrasonic frequencies. Other sensations appeared equally much within 4–63 Hz. This suggests that hearing at infrasonic and non-infrasonic frequencies is basically similar.

The reviews of Broner (1978), Møller & Pedersen (2004), Leventhall (2009), and HPA (2010) support the view that infrasound perception and health effects do not differ from those of non-infrasound. This study agrees with these previous reviews because of three reasons. First, the HTL could be determined also for infrasonic frequencies meaning that infrasound is not inaudible. Second, the annoyance of tones of infrasonic frequencies increases similarly as a function of increasing SPL, which means that annoyance perception behaves normally. Third, other sensations apart from hearing were not limited to tones of infrasonic frequencies but appeared up to 63 Hz.

Therefore, the need of term “infrasound” can be questioned since it is misleading. Presence of infrasound may cause unfounded horror and concern among citizens. Although the behavior of hearing becomes different towards lower frequencies, there is no justification to draw a division line at 20 Hz.

To facilitate the authorities’ assessment of health effects of low-frequency noise, national target values for night-time noise inside residential dwellings would be useful also below 20 Hz. Hongisto (2022) has proposed the values of Table 3 to be considered in the next revision of Finnish health-based target values. The values are based on the HTL of normal hearing adults of Fig. 2 reduced by 5 dB. It is expected that 84% of normal-hearing people do not hear the sound if the SPL is below Table 3.

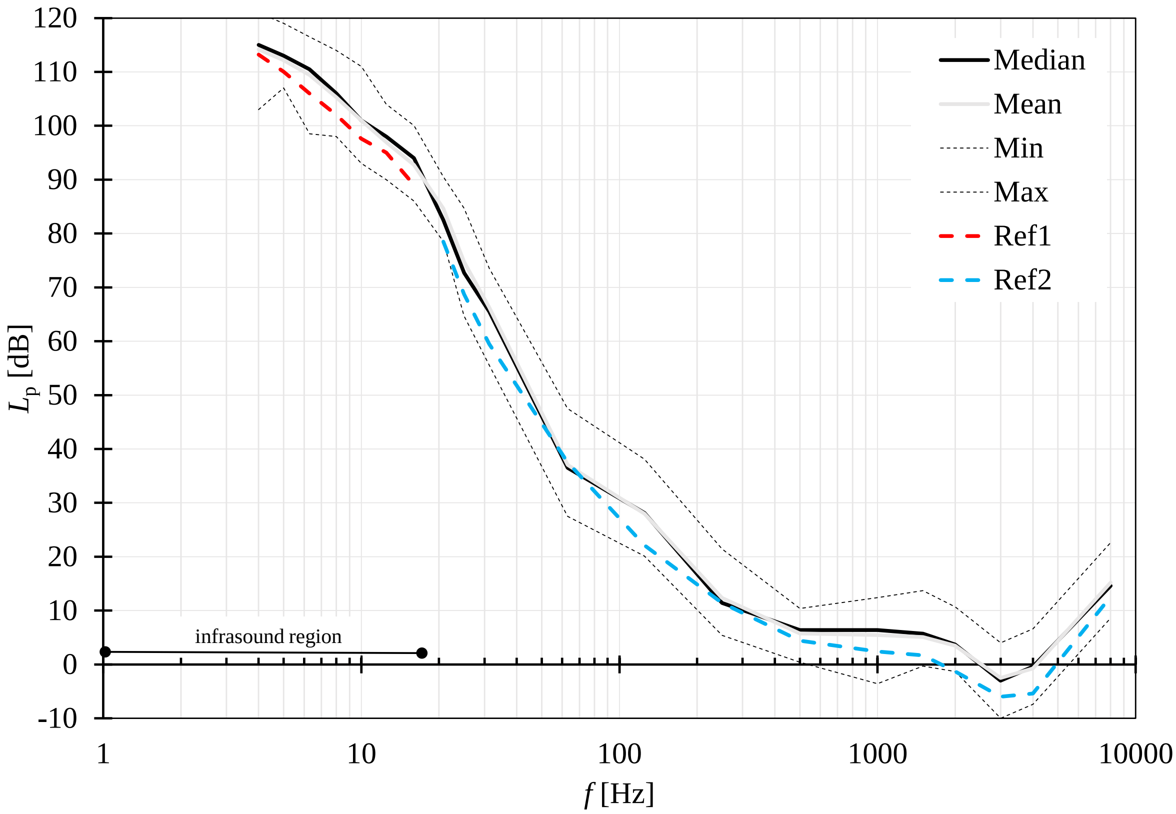

Fig. 2. The sound pressure level of the hearing threshold (HTL), L_p, as a function of frequency. Median, Mean, Min and Max are based on the data of 19 participants. Comparison is made to Møller and Pedersen (2004) within 4–16 Hz (Ref1) and to ISO 226 (ISO, 2003) within 20–8000 Hz (Ref2).

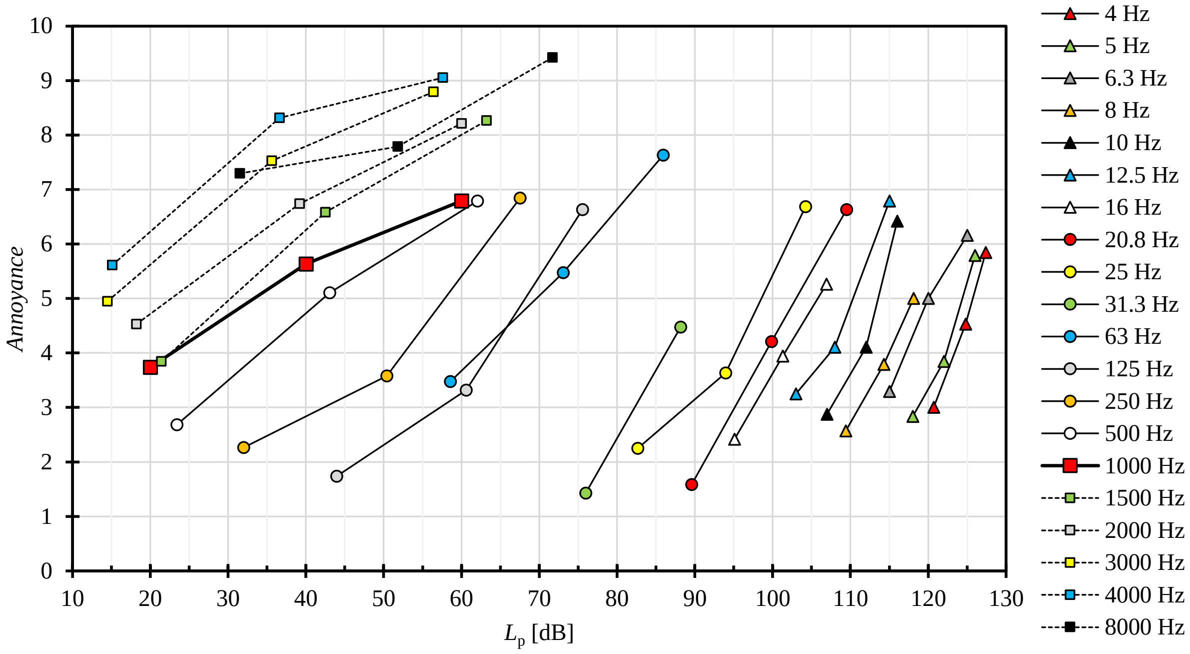

Fig. 3. The mean *annoyance* of 19 participants as a function of unweighted SPL, L_p, for the 20 studied tone frequencies, *f*. For each frequency, the three SPLs conformed with the equal-loudness values 20 phon (smallest value of each dataset), 40 phon (middle value), and 60 phon (largest value) given in Table 1. The *annoyance* response scale was from 0 (Not at all) to 10 (Extremely annoying).

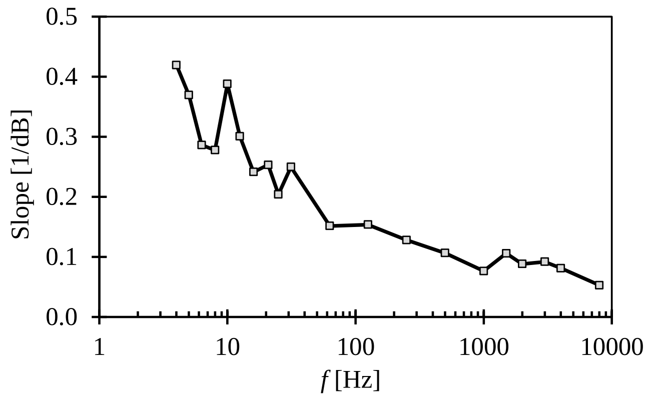

Fig. 4. The slopes of the annoyance vs. level curves of Fig. 3 as a function of frequency.

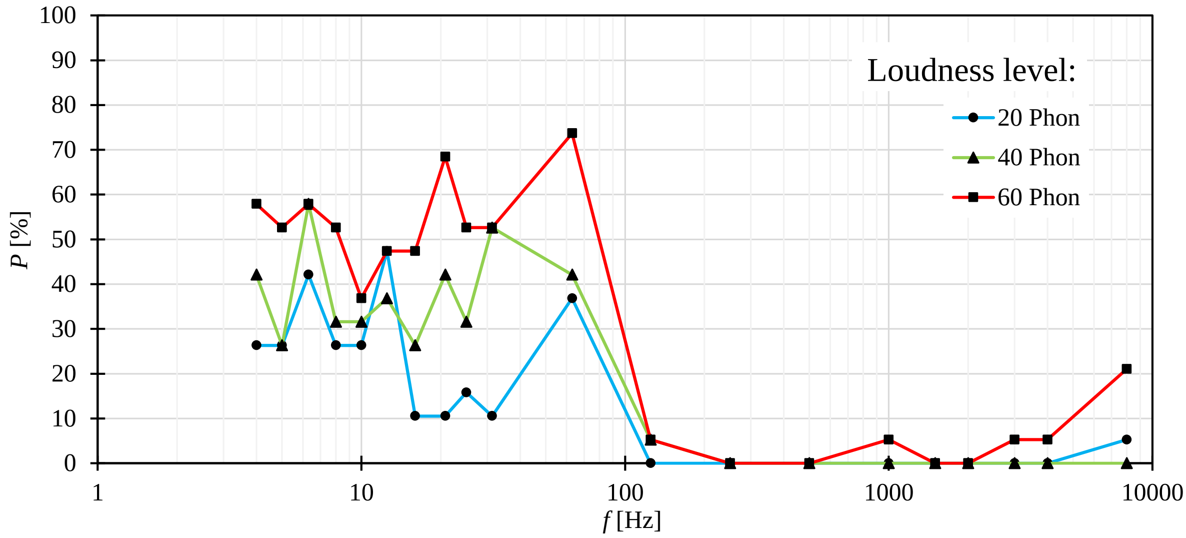

Fig. 5. Probability *P* of reporting other sensations apart from hearing as a function of frequency, *f* inquired in Phase 10. The number of other sensations is not yet known in this data.

Table 2. Summary of the other sensations apart from hearing, which participants described verbally in Phase 11 after hearing again those tones that caused such sensations in Phase 10. This table uses unified sensation names since participants used different expressions for the same sensation. The list does not explain the number of sensations.

f [Hz]	20 Phon	40 Phon	60 Phon
4	1,2	1, 5	1, 2, 3, 4, 5
5	1,2	1	1,2,3,5
6.3	1, 2, 4	1, 2, 4	1, 2, 3, 4
8	1, 2	1, 2	1, 2, 3, 4
10	1, 2	1, 2	1, 3, 4
12.5	1, 2, 4	1, 2	1, 2, 3, 4
16	1, 2	1, 2	1, 2
20.8	2	1, 2, 5	1, 2, 4
25	1	1, 2	1, 2
31.3	2	2	2, 3
63	2	2	2
1500			3
4000			4
8000			4

ID	Sensation
1	Pressure in the ear and/or head
2	Vibration sensation
3	Ear pain
4	Headache
5	Feeling of airflow

Table 3. Proposal for target values (highest allowed values) in rooms used for sleeping during night-time hours.

f [Hz]	4	5	6.3	8	10	12	16
$L_{eq,1h}$ [dB]	109	107	104	100	96	92	88

CONCLUSION

Based on this study, perception of infrasound frequencies 4–16 do not essentially differ from the perception at 16–20 Hz or other low frequency sounds. Although the behavior of hearing becomes different towards lower frequencies, there is no justification to draw a division line at 20 Hz. Therefore, the term infrasound is misleading and useless from audiologic point of view and should be removed in all communications.

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