inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 6.2

HUMAN EFFECTS OF INFRASOUND

U. Landström

National Institute for Working Life, Box 7654, S-907 13, Umeå, Sweden

Tel.: S-090-7865096 / Fax: S-090-7865027 / Email: ulf.landstrom@niwl.se

Keywords:
INFRASOUND, EFFECTS

ABSTRACT
The risk for hearing impairments due to infrasonic exposures at normally occurring sound pressure levels is low. In cases where hearing impairment has been shown, it has often been of a short-term nature, lasting for less than one hour. Unpleasant experiences of pressure in the middle ear are often mentioned in connection with exposure to infrasound. The effect can be explained as an increased vascular pressure in the middle ear due to over production of endolymph. The prerequisite for annoyance, disturbance effects, diffuse unpleasantness, reduced ability to concentrate etc., is that the exposure level is above the level of perception via the hearing. Studies have also shown an increased risk of drowsiness during exposure to infrasound. Changes in wakefulness can be described as a connection between hearing perception, the reticular activation centres of the brain and following cortical functions.

1 - PROPERTIES AND OCCURRENCE
Infrasound consists of sound waves with frequencies under 22 Hz. Wavelengths within the infrasound field vary from 340 m (1 Hz) to about 17 m (20 Hz).
As with other types of sound, infrasound is produced by movements in fixed, liquid or gaseous media. In nature, infrasound can be produced by inter alia thunderstorms, winds, volcanic eruptions, earthquakes and waterfalls. The exposure to which humans are today subjected, is largely the result of widespread industrialisation and technical development. The number of infrasound sources has increased markedly in recent years, in spite of the fact that infrasound itself has only been used to a small extent [1]. Infrasound is in most cases an undesirable sound and is therefore usually characterised as noise.
Through turbulent currents, rocking motions in gases, liquids or solid bodies, infrasound can be spread from a number of different sources. The suppression of its distribution in air is low. The long wavelengths also mean that screening can only to a small extent prevent the spread of infrasound.
Examples of common infrasound sources are ventilation systems, jet engines, the release of gas or steam under high pressure, electrodes, oil burners, vehicles, diesel engines, compressors, machines with rocking parts and rocking water bodies in power stations. The acoustic pressure levels in the environment around plant of this type are strongly affected by the resonances produced. The design of machine rooms, driver's cabs, manoeuvre rooms, work premises, ventilation channels etc. is of great importance in this context.

2 - HYGIENIC ASSESSMENT FOR INFRASOUND
Current Swedish regulations for infrasound exposure are found in the National Board of Occupational Safety and Health statute book for noise [2]. On exposure to the infrasound frequency field, a number of highest recommended third levels apply. The proposed exposure values for infrasound are based on an assessment with regard to the perception threshold curve for infrasound. Infrasound under the perception threshold is not deemed to cause any problems. The acoustic pressure levels are shown for every middle frequency in 1/3 octave bands from 20 Hz (90 dB) to 2 Hz (130 dB). The weighting is thus 4 dB/third octave band. Depending on the limit areas for the lowest and highest third octave band, the infrasound field will, from an evaluation point of view, comprise the area 1.8 - 22. Hz.

3 - HUMAN EXPERIENCE OF INFRASOUND
Perception in the infrasound field requires high acoustic pressure levels - the lower the frequency, the higher the level for perception [3, 4]. The tonal auditory experience ceases at about 15 Hz. The length

and structure of the inner ear of the auditory apparatus is the foremost reason for the limited hearing ability of the human being. Humans do not however lack the ability to perceive sounds at even lower infrasound frequencies [5, 6, 7]. The perception threshold for the infrasound field can be coupled to previously described hearing curves for higher frequencies. Individual variations exist of the experience of infrasound. As with other types of sound, certain individuals seem to be noticeably more sensitive and perceptive than others [8].

The sound experienced, as previously mentioned, lacks a tonal character for frequencies under 15 Hz. The sound is instead experienced as a form of repeating shocks or pressure waves. The perception of infrasound would thus be based on repeating distortion effects in the middle and inner ear, rather than heard pure infrasound tones. Since the hearing experiences of infrasound are probably based on distortion and overtones in the middle ear, masking via higher frequencies can sometimes occur. Studies have shown that 7 Hz, 120 dB can be masked by I 10 dB 10-100 Hz background sound [4], [9, 10].

The perception of infrasound is also in some circumstances based on produced vibrations. For production of bodily resonances and perception in the abdomen or chest region, however, higher acoustic pressure levels are required than those necessary for hearing perception [11, 12]. For the production of vibrations in the abdominal area, levels around 120 - 140 dB are required in the frequency area 2-20 Hz [4].

The prerequisites for bodily vibrations during infrasound exposure vary between different tissues, which is reflected in the various threshold levels but also various types of effects. A prerequisite for the production of bodily vibration through infrasound is that the tissue encloses gas, usually air. Examples of tissues which are mechanically most easily affected by the pressure variations of infrasound are lungs, sinuses, gas-filled intestines or stomach, and the middle ear. In the registration of infrasound via vibrations, various types of perceptive systems are used, for example deep-lying sensory receptors (pacinian corpuscles), joint receptors, muscle spindles, golgi cells, or various types of sensory receptor in the skin.

4 - EFFECTS OF INFRASOUND ON OUR HEARING

The effects of infrasound on human beings have been the object of discussion for a long time. On account of the often hard-to-define hearing experiences produced by infrasound, much interest has been focused upon possible hearing damage. Thorough hearing tests were carried out by von Bekesy as far back as the 1930s [5].

TTS tests (Temporary Threshold Shifts) which have been carried out give however a picture which is difficult to interpret. The result of hearing tests can be summarised by saying that the infrasound only seems to give permanent effects on registration of "audible" frequencies to a small extent. In those cases where hearing impairment has been able to be proven, it has often been of a short-term nature, lasting for under an hour [13]. In extreme infrasound exposure over 140 dB, the hearing experience seems to be affected for all frequencies above 125 Hz. The most clear reduction of hearing takes place within the field just over 1 kHz [14, 15]. Studies have shown that 140 dB (4-20 Hz) can produce a threshold shift of 10 dB at frequencies around 1,000 Hz [16].

The experience of unpleasantness or pain which can be localised to the ear and which is produced by infrasound is above all due to mechanical overload of the structures of the middle ear [16, 17]. The threshold for tissue damage in a previously uninjured middle ear is deemed to lie at around 140 dB for 20 Hz and around 160 dB for 2 Hz. Exposure of the human being should however not exceed 150 dB, this to avoid direct tissue damage to the eardrum or the structures of the middle ear (Johnson 1980).

Unpleasant experiences of pressure in the middle ear are often mentioned in connection with exposure to infrasound. The unpleasantness seems to arise at levels around 125-130 dB ([9], [11], [18,19,20]). The problems remain for a while after exposure has ended. The effect can be physiologically explained as an increased vascular pressure in the middle ear on account of overproduction of endolymph. The pressure also reduces hearing for a time. The excess endolymph does however eventually disappear, leading to normalisation of hearing.

5 - DISTURBANCES CAUSED BY INFRASOUND

The first scientific assessments of infrasound were done during the first world war when it was suspected that certain negative effects could arise upon infrasound exposure. Among the first effects described on human beings were general symptoms of disturbance, such as diffuse unpleasantness, mental imbalance, reduced ability to concentrate, increased frequency of error, reduced performance, etc. Uncertainty surrounding the interpretation of the results of these studies of experience and disturbance has often been emphasised. Some connection between exposure to infrasound and disturbance has been deemed established however [21,22]. The prerequisite for the origin of disturbance effects, diffuse unpleasantness, mental imbalance, reduced ability to concentrate etc., is that the level of exposure is above the level of perception via the hearing ([1], [3], [23]).

The perception threshold thus also constitutes a rough measure of the lowest levels for the origin of experienced disturbance. The proposed risk curve for disturbance experiences largely follows this perception level curve ([8], [10], [24,25,26,27]).
Studies have shown that the changes in experience on account of infrasound are produced within considerably narrower acoustic pressure level limits than for other sounds. Within the infrasound area, around 5 dB seems sufficient for a doubling/halving of the experienced volume.
Some other differences between infrasound and other sound frequencies can also be mentioned, inter alia that adaptation or accustomisation to the infrasound seems more difficult than adaptation to higher sound frequencies. Adaptation and habitualisation thus seem lower throughout for infrasound and low-frequency noise compared to higher sound frequencies.
The source of production of the infrasound is also many times harder to identify than the source of high-frequency sound. Inability to identify the source of the sound is often felt to be disturbing [1].

6 - PHYSIOLOGICAL EFFECTS OF INFRASOUND

Among the physiological effects of infrasound which have been the main object of discussion in recent years is changes in wakefulness. Studies have shown an increased risk of drowsiness during exposure to infrasound.
Changes in wakefulness can be described as a connection between perception, the reticular activation centres of the brain, and cortical functions [28]. According to present theories, human beings' cortical activity is controlled by the brain stem's so-called reticular activation centres (RAS). The ability of various environmental factors to affect the brain's activation centres, and thereby our wakefulness, in different ways is a clear factor in our everyday life (Borredon 1980). Some connections can be seen to have been established by experience. Monotonous, subdued, repetitive stimulation is often experienced as contributing to drowsiness. Powerful, irregular stimulation is often felt to contribute to wakefulness. Laboratory trials and field studies have shown a positive correlation between exposure to infrasound with acoustic pressure levels close to the perception threshold and reduced wakefulness [29,30]. Drowsiness effects seem particularly clear at levels just above the perception threshold for hearing experience. At high acoustic pressure levels, waking effects are produced, as expected. The waking effect is followed by simultaneous changes to blood pressure and pulse. During exposure to infrasound, with reduced wakefulness as a consequence, reduced pulse as well as reduced systolic and diastolic blood pressure have been noted [31]. All of these reaction patterns are normal physiological changes produced during falling asleep [32,33]. Changes are controlled partly by specific centres in the brain stem. The results, in other words, support the theory of a connection between perception, central nervous functions and physiological effects.
The occurrence of individual thresholds for perception and thereby production of effects must be emphasised however. In practice, exposure to noise usually takes place in the form of complex sounds, i.e. exposure to broad frequency bands with varying levels. The masking effect of simultaneous sounds at higher frequencies must also be taken into account. The tiredness-inducing effects of infrasound in for example vehicle cabs or manoeuvre rooms are deemed in later studies to be able to be blocked by noise from higher sound frequencies [34].
Whether the noted increase in hydrochloric acid production in some test persons [31] is based on bodily resonances and vibrations in the stomach remains to be proven.
The effects of infrasound on breathing and the hydrochloric acid production of the stomach's mucous membranes are limited and only seem to occur in certain people [30]. Studies agree in this respect with behavioural studies according to which some individuals show considerably greater reactivity to infrasound than others ([1], [3], [8], [10]).
Present knowledge of the physiological effects produced by infrasound are largely based on exposure carried out in laboratory conditions. Experience of effects produced in working environment-type conditions are relatively few. What is above all almost wholly lacking is definite knowledge of the way in which human beings are affected by long-term infrasound exposure.

REFERENCES

1. **H.G. Leventhall**, The occurrence, measurement and analysis of low frequency noise, *Conference Low Frequency Noise and Hearing*, 1980

2. **Swedish National Board of Occupational Safety and Health**, *Noise*, Swedish National Board of Occupational Safety and Health, 1992

3. **D. Johnson**, The effects of high level infrasound, In *Low Frequency Noise and Hearing*, 1980
4. **U. Landström and al**, Exposure to infrasound - perception and changes in wakefulness, *Low Frequency Noise Vibration*, Vol. 2, 1983
5. **G. Bekesy von**, Experiments in Hearing, *E.G. Wever, Mc Graw-Hill, New York*, 1960
6. **N.S. Yeowart and al**, Low frequency noise thresholds, *The Journal Sound of Vibration*, Vol. 9, 1968
7. **N.S. Yeowart**, Low frequency threshold effects, In *Fall Meeting of British Acoustical Society*, 1971
8. **O. Okai and al**, Physiological parameters in human response to infrasound, In *Low Frequency Noise and Hearing*, 1980
9. **D.L. Johnson and al**, The audibility of infrasound, In *Acoustical Society of America Fall Meeting*, 1974
10. **S. Yamada and al**, Hearing of low frequency sound and influence on human body, In *Low Frequency Noise and Hearing*, 1980
11. **R.N. Slarve and al**, Human whole body exposure to infrasound, *Aviat. Space Environ Med*, Vol. 46, 1975
12. **C.S. Harris and al**, Effects of infrasound on cognitive performance, *Aviat. Space Environ Med*, Vol. 49, 1978
13. **G. Anon**, Public health and welfare criteria for noise, *UIS E.P.A. Report*, Vol. 550/9–73-002, 1973
14. **D.L. Johnson**, Auditory and physiological effects of infrasound, In *Inter-Noise*, 1975
15. **B.O. French and al**, Effects on low frequency pressure fluctuations on human subjects, *NASA*, Vol. TN-3323, 1966
16. **C.W. Nixon and al**, Infrasound and hearing, In *International Conference on Noise as a Public Health Hazard*, 1973
17. **C.W. Nixon**, Human auditory response to intense infrasound, In *Colloquium of Infrasound*, 1973
18. **G.C. Morh and al**, Effects of low frequency and infrasonic noises on man, *Aerospace Med*, Vol. 36, 1965
19. **P.M. Edge**, Description of Langley low frequency noise facility and study of human response to noise frequencies below 50 cps, *NASA*, Vol. TN D-3204, 1966
20. **H.E. Gierke von and al**, Aural pain produced by sound, *Benox Report, Contract N6cri-020, Task Order 44, ONR Project No 144079*, 1953
21. **P. Borredon and al**, The psychological effects observed on man exposed to an infrasonic level of 130 dB, In *International Colloquium of Infrasound*, 1973
22. **K. Kyriakides and al**, Some effects of infrasound on task performance, *Journal of Sound and Vibration*, Vol. 50, 1977
23. **P. Borredon**, Physiological effects of infrasound in our everyday environment, In *Low Frequency Noise and Hearing*, 1980
24. **H. Møller**, The influence of infrasound on task performance, In *Low Frequency Noise and Hearing*, 1980
25. **J. Andresen and al**, Annoyance of infrasound, In *Inter-Noise*, 1983
26. **S.J. Collins and al**, The audibility of low frequency sounds, *Journal of Sound and Vibration*, Vol. 21, 1972
27. **H. Møller and al**, Loudness of infrasound, In *Inter-Noise*, 1983

28. **E. Grandjean**, *Précis d'ergonomie*, Organisation Physiologique du Travail, ed Dumond, 1969

29. **R. Fecci and al**, Effects of infrasound on the organism, *La Medicina del Lavoro*, Vol. 62, 1971

30. **U. Landström**, *Human exposure to infrasound*, Encyclopedia of Environmental Control Technology Gulf Publishing Company, Houston, ed P.N. Cheremisinoff, 1994

31. **U. Landström**, Some effects of infrasonic noise on man, In *Low Frequency Noise and Hearing*, 1980

32. **J. I. Lacey**, Individual differences in somatic response patterns, *Journal of Comp. Physiol.*, Vol. 43, 1950

33. **W. T. Liberson and al**, EEG records, reaction time, eye movements, respiration and mental concent during drowsiness, *Recent Adv. Brol. Phychiat.*, Vol. 8, 1966

34. **U. Sandberg**, Combined effect of noise, infrasound and vibration on driver performance, In *Inter-Noise*, 1983