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The Effects of Low Frequency Noise in Transportation

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Introduction The organs of the inner ear, comprising the cochlea, the otolith system and the semi-circular canals, respond in normal life to different frequency ranges. The cochlea is usually regarded as responding to pressure changes in the form of acoustic waves from 20Hz upwards, the otoloith system will respond at rest to the force of gravity, which implies that it has a 'D.C.' response, while the semi-circular canals have a response region between these two extremes. However, the frequency response of each system is not a sharply defined limit, but merely the frequency at which the response is appreciably reduced, the distinction drawn between the three organs in terms of frequency response is therefore not absolute and each system will respond, although to a lesser extent, outside its normal rarge.

It is found experimentally that both tone and noise signals in the range 1-20hz give rise to a conscious sensation, somewhat akin to hearing or to feeling, the precise origin of this sensation is not clear. This 1-20Hz frequency range also covers the sensitive range of the semicircular canals and the upper part of the range of the otolith system, it therefore seems possible that infrasound may affect the static and dynamic labyrinths. This proposition has now received considerable experimental support.

Apparatus Equipment has been developed in this laboratory to generate intense infrasound with closely controlled acoustic parameters. The apparatus consists basically of suitable large loudspeaker units, one to each ear, coupled directly to headphone-type noise excluding earcups. Provided precautions are taken to ensure an adequate seal between the earcups and the head sound pressure levels approaching 150db can be generated at frequencies down to 1Hz. The associated electronic equipment can provide both random noise and pure tone signals and the levels of harmonic distortion, hum and unwanted high frequency noise are low enough to permit reliable determinations of the detection thresholds.

M.A.P. Thresholds The M.A.P. thresholds for pure tones down to 1.5 hz and for octave bands of noise down to 4Hz were determined using the constant stimulus technique (1,2). The main results of this (monaural) experiment are shown in figure 1. Considering first the tone thresholds, the most obvious result is that the threshold continues to rise smoothly with decreasing frequency right down to the lowest frequency included in the experiment. The initial rise, at frequencies above 16hz, is at about 18dB per octave, while at lower frequencies the rise takes place at about 12dB per octave. The observers were asked to describe what they heard at the various frequencies and the replies, although somewhat varied, can be summarized as follows

Above 20 Hz	Smooth, tonal
Between 15 and 5 Hz	Popping sound
Below 5 Hz	Chugging, whooshing.

Both the change in slope at 18hz and the departure of the sound from a tonal character at 15-20 Hz suggest that there is some change in the nature of the subjective experience at this frequency, and presumably a corresponding change in the detection process at the same time. This view receives support from the work of Brecher (3) who reports the existence of a 'fusion' frequency at 18Hz above which sounds have a tonal character and below which they do not.

The noise thresholds, obtained with octave band gaussian noise, show a very interesting effect in that they are not significantly different from the tonal thresholds at frequencies of 32Hz and above, but at 16Hz and below they tend to depart from the tones, the noise threshold being several dB more sensitive. An experiment designed specifically to investigate the tone-noise differences in threshold showed that at 16Hz and below the differences were of statistical significance (p less than 0.001) and led to consideration of a possible explanation of the differences. It was concluded that the effect could be explained if it were assumed that the ear detects the peak levels in the signal at these very low frequencies. A circuit model of the ear, including a time constant of 200mS and a detector accurately reproduced the relative tone-noise threshold difference.

Infrasonic effects on the organs of equilibrium Basically the same apparatus as was used in the threshold work was available for the study of the effects of infrasound on the sense of balance.

One of the most easily recorded and reliable indications of any disturbance of balance is the occurrence of involuntary eye movements, and particularly of nystagmus. Initial experiments have therefore been concentrated on recording eye movements under infrasonic stimu-lation. Normal electronystagmographic techniques are used to record any vertical or horizontal eye movements, although for practical reasons most experiments have been limited to either one or the other.

Experimental procedure The first stage of each experiment was a five minute period in which the observer sat in the darkened test room while the pattern of eye movements was examined, at this stage no stimuli of any kind was applied. Some observers exhibited a spontaneous nystagmus, or were disturbed by the experimental conditions, and were asked to terminate the experiment at this point. Low frequency tones were then applied monaurally and the effects on eye movement were recorded. After the test each observer was asked to describe his subjective impressions.

Each test included a range of stimulus frequencies, intensities and stimulus durations, and separate experiments were performed to measure horizontal and vertical eye movements in each of two body positions, sitting upright in a chair and lying flat, face upwards, with the head raised slightly. Each experiment was repeated with the eyes open and closed.

Results Of the four experiments outlined above (horizontal and vertical eye movements in each of two body positions) only one, the measurement of vertical eye movements in a sitting position produced any well-defined eye movements in normal observers. In this experiment Sound Pressure Levels ranged from 130 to 146dB, frequencies from 2 to 10Hz and stimulus durations from 5 to 60S.

Some 25 normal observers took part and produced a variety of responses which are set out in tabular form below.

Reaction	Number of Observers
Nil	1
Spontaneous nystagmus with the eyes open	2
Excessive blinking masking other responses	5
Small nystagmic response (difficult to identify)	10
Clear nystagmic response	7

The subjective response reported by a number of the observers was one of swaying. Two other rather brief experiments also merit a mention here. The first was on two observers who reported that they had some abnormality of balance, both being easily subject to balance disturbances. In both cases it was found that infrasound caused such a violent disturbance and sensation of nausea that the experiment had to be discontinued, the actual levels involved in the tests being 105dB at 2Hz and 140dB at 1Hz respectively. The other experiment, still at a preliminary stage, is the application of a binaural signal to a group of normal observers. In this case 7Hz signals (found to be the most effective frequency) were applied to five normal observers, in all cases levels of 140 dB were sufficient to produce a positive vertical nystagmic response.

Conclusions In the case of the threshold work described first in this paper, no satisfactory conclusion as to the site of the detection process has been reached. The observers' own comments, that the experience is similar to a physical movement of the tympanic membrane suggest that detection may be essentially a process of feeling, however this view is not supported by the fact that at the lowest frequency tested the threshold is still changing at about 12dB per octave; the feeling hypothesis would lead one to expect a flat response to frequency, once the pressure had reached the feeling threshold.

The work on balance disturbance, which is still at a preliminary stage, shows that intense infrasound at around 7Hz seems to produce a balance disturbance in most individuals and the resulting vertical nystagmus, together with the report of a swaying rather than a spinning sensation suggests that the otolith system rather than the semi-circular canals may be responsible. The small magnitude of the effects produced in normal observers seems to indicate that the levels used (up to 140dB binaurally and 146dB monaurally) are only just exceeding the threshold for the effect. Parker et al,[4] in some work at higher intensities (up to about 165dB) on guinea-pigs have found nystagmus, eye-rolling and eye-movements in synchronism with the stimulus. This result fits in with our hypothesis that our own work is in fact only just reaching the threshold for balance disturbance.

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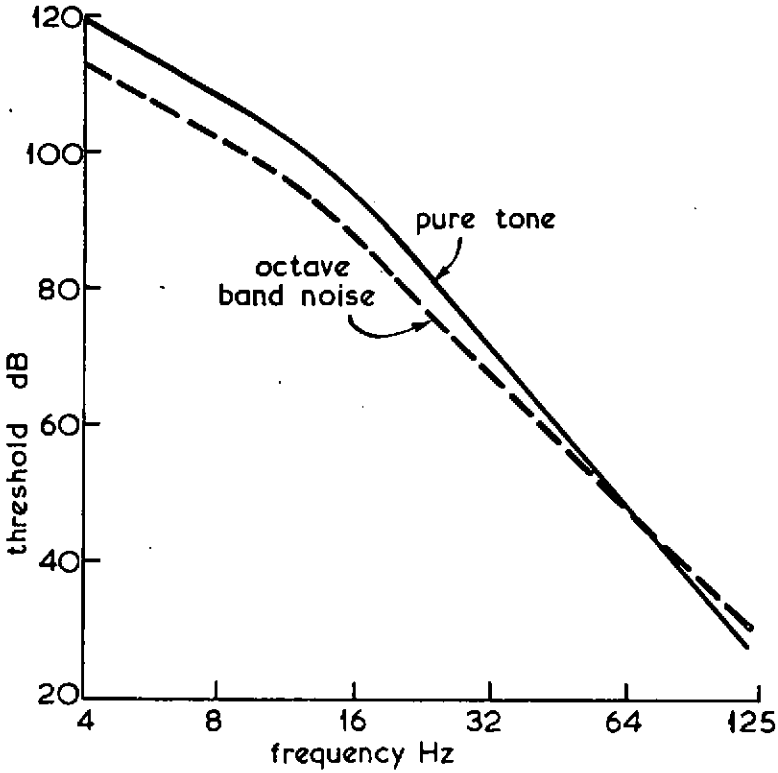

Fig.1 Low frequency 'hearing' thresholds.