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THE EFFECTS OF LOW FREQUENCY NOISE ON PEOPLE–A REVIEW†

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During the last few years, the existence of high levels of man-made low frequency noise (0–100 Hz), and in particular infrasonic noise, has been reported in many environments. An effort has been made over the last decade to discover whether such high levels of low frequency noise are significant. A review of the effects of low frequency noise indicates that the effects are similar to those of higher frequency noise, that noise in the 20–100 Hz range is much more significant than infrasound at similar sound pressure levels and that the possible danger due to infrasound has been much over-rated.

1. INTRODUCTION

During the last few years, many sources of high level low frequency noise (0–100 Hz) have been identified and many of these sources exhibit a spectrum which shows a general decrease in sound pressure level with increase in frequency [1, 2]. Further, man-made sources of low frequency noise such as compressors, boilers, cars and ships, appear to present a potentially greater hazard than natural sources such as wind, turbulence, storms and earthquakes. Certainly, subjective reports of effects due to infrasonic exposure to man-made sources have indicated that nausea, disorientation and general unpleasantness, as well as a variety of other symptoms, can occur. But because of the unknown possible effects due to low frequency noise, an effort has been made in the last decade, spurred on by the reported results of Gavreau, Condat and Saul [3], to discover whether in fact harmful low frequency noise effects actually do occur. In what follows here the information available on low frequency, and in particular infrasonic, noise is reviewed, with some emphasis on putting into perspective the sensational approach of the popular press to infrasound.

2. ANNOYANCE

The primary effect due to low frequency and infrasonic noise appears to be annoyance, at least for the lower sound pressure levels, and many instances of such annoyance have been reported. Gavreau [4] even went so far as to attribute modern-day "city fatigue" to infrasound exposure. Generally, however, the annoyance has been more specific and has occurred even where the dB(A) level has been relatively low. For example, Bryan [5] found that two residents living near a factory boiler were being annoyed even though the level outside their houses was only 55 dB(A). Other low frequency noise nuisance problems have been caused by such sources as the Concorde engine test bed, air-conditioning systems and oil-fired burners and boilers [6–16]. Response to this low frequency noise has varied from sleep disturbance and general annoyance to reported "threats of suicide" in otherwise disturbed people, [10, 17–23].

† This research was completed at the Department of Mechanical Engineering, Monash University, Australia.

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A number of cases have been investigated by the author and in one of these cases it appeared that the central heating unit was causing a low frequency noise which annoyed the wife in a neighbouring house so that she could not sleep, although the husband was undisturbed. The overall sound pressure level (*OASPL*) in the bedroom, which was 6 m from and facing the unit, was found to be 63 dB but only 32 dB(A) (Figure 1). It appears that the peak at 54 Hz was responsible for the disturbance in this case.

There is also one area of West London in which complaints of low frequency noise annoyance occur regularly, though the problem appears to be a national one. A recent report in the London *Sunday Mirror* brought an initial response of over 700 letters, many of which also described annoyance due to the existence of a low frequency rumble, and in some cases, due to a feeling of pressure on the ears [24–26].

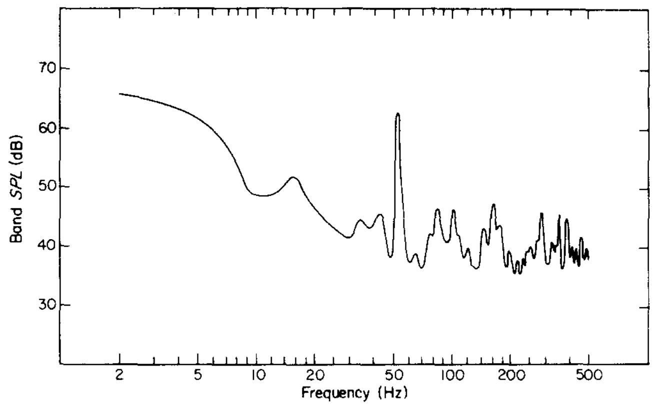


Figure 1. Noise spectrum (2 Hz constant bandwidth) measured in a bedroom and which caused annoyance.

It is therefore apparent that the annoyance due to low frequency noise which is experienced by sensitive people is more common than previously believed. Bryan [5] and Tempest [27] have noted that for noise containing high levels of low frequency noise, the common assumption that loudness and annoyance are equivalent breaks down and that such measures as dB(A) cannot then predict annoyance. Kraemer [28] carried out a paired comparison test in which the subjective response to low frequency sound in the range 25–125 Hz was measured and the results showed an increase in annoyance with low frequency noise for constant dB(A) levels. Peaks in annoyance at certain combinations of frequency (30–50 Hz) and level (65 dB(A)) were indicated and these were attributed to interacting effects of loudness and annoyance. It should be noted, however, that the range of levels used in this study was limited to 55–75 dB(A). Kraemer's results are in fact partially supported by Vasudevan and Gordon [29], who, when investigating a disturbance heard as a "throbbing" sound, indicated that the phenomenon arises with a broad band spectrum which is unbalanced to the extent that the major stimulus occurs in the frequency range 20–100 Hz. Their tests suggested that the throbbing noise lay in the 30–40 Hz frequency range. Also recently, in discussing low frequency noise annoyance, Bryan [30] reported that sufficiently widespread annoyance has arisen in all three environments of transportation interiors, work and home that it could be concluded that this annoyance did not arise from any peculiar sensitivity of individuals exposed but was due to the type of noise producing the annoyance. Bryan suggested that it was the slope and "turnover point" of the noise spectra of these low frequency noises rather than their absolute levels which could be important in determining annoyance. This follows from the fact that there is a wide range in the latter, from 120 dB inside motor vehicles down to 60 dB inside the houses in the neighbourhood nuisance problems, and yet the same type of disturbance is produced at all levels. Clearly, this idea is speculative and work is currently in progress at Chelsea College which should help to clarify this issue.

As regards a threshold level for annoyance, both Johnson [31, 32] and Leventhall [33] expressed the thought that "if you can't hear it, you can't feel it", and this led Johnson to the criterion shown in Figure 2. The L_{DN} of 55 dB was set as a limit for audio frequencies [34] and was extrapolated down to low frequencies. The limit of 120 dB was chosen for frequencies below 5 Hz to avoid middle-ear pressure build-up and damage to or rattling of structures. However, people who show extreme sensitivity to higher frequency noise may not be wholly protected by this criterion.

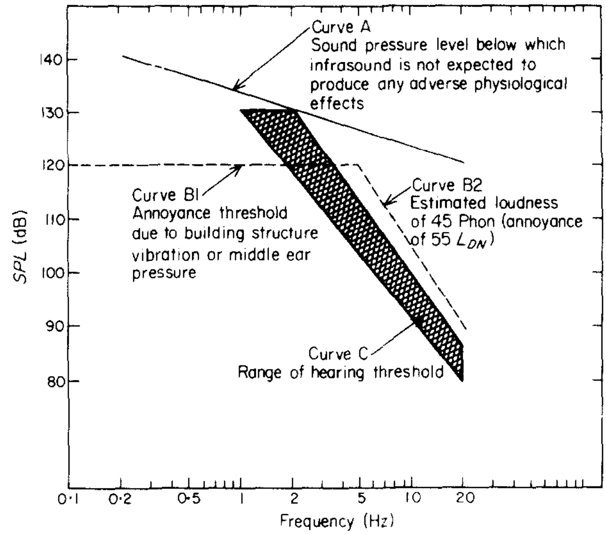


Figure 2. Infrasound criteria proposed by Johnson [31, 61].

3. HEARING

Auditory system response has long been a criterion for measuring the acceptability of noise exposure, and much work has been done in this regard for low frequency noise, and in particular, infrasound.

3.1. HEARING THRESHOLD LEVEL

One of the most common misconceptions regarding infrasound is that it cannot be heard, but this is not the case. Perhaps one of the most long-standing descriptions for hearing threshold levels (MAP) including infrasonic frequencies is that given by Bekesy in 1936 (see reference [35]), and since then many investigators, using a variety of instrumentation, have independently measured low frequency hearing thresholds [36–42]. Some of the results are shown in Figure 3 and it can be clearly seen that infrasound can be heard down to 1 Hz and below provided that the sound pressure level is high enough. However, as infrasonic pure tones appear to be perceived as a "chugging", "rough" or "popping" sound, Johnson and Von Gierke [43] and Johnson [31] suggested that a person does not "hear" tones of infrasound but rather the associated harmonics generated by distortion of the middle and inner ear. Thus, according to them, as infrasound is rarely unaccompanied by higher masking frequencies, it is possible to explain why infrasound may not be normally "heard".

Other findings have been that the classical MAP–MAF difference of 3 dB for audio frequencies is also present for low frequency noise [42] and that between 30 and 100 Hz, no

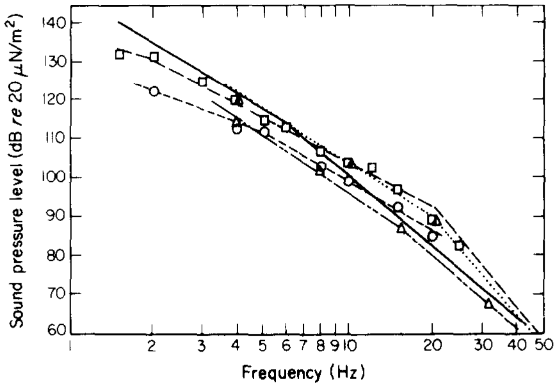


Figure 3. Hearing threshold levels for maximum audible pressure (MAP), minimum audible field (MAF) and for bands of noise (after Nixon and Johnson [51]). ——, Bekesy, MAP; □, Yeowart, MAP; ○, Yeowart, MAF; ▲, Yeowart tone threshold; △, Yeowart, noise threshold.

significant difference exists between tone and noise threshold data. It has also been established that below 16 Hz, where detection depends on pressure peaks in the noise signal, that the noise thresholds are 4 dB more sensitive [38].

3.2. TEMPORARY THRESHOLD SHIFT (TTS)

A quantitative relationship between human exposure to infrasound and hearing loss is not well established and this is partly due to the general inability to produce infrasound exposures free of audible overtones. It is likely, though, that the adverse effect of infrasound alone could be no worse than that due to infrasound plus overtones, and for this reason little attempt has been made to distinguish effects. One of the earliest observations was made by Tonndorf [44] and since then many studies have been conducted in only some of which has TTS been measured [45–52]. For example, Ramet [53] found no TTS due to a 40-min exposure to a low frequency noise (2–15 Hz) at 115 dB *OASPL*, while Alford *et al.* [47] noted a TTS greater than 10 dB in 11 of 21 subjects exposed for 3 min to 2, 10, 12 and 22 Hz tones at levels greater than 137 dB *SPL* (there was one exception of a subject who had a 13 dB TTS at 6 kHz after a 129 dB exposure to 22 Hz). So it appears that (i) only small, if any, TTS can be observed following exposure to moderate and intense infrasonics, and (ii) recovery to pre-exposure hearing levels is rapid when TTS does occur [54]. Finally (iii), for infrasonic exposures above 140 dB, TTS of the audiometric frequencies above 125 Hz may occur, although the frequencies above 1 kHz seem more sensitive [31, 48].

3.3. AURAL PAIN AND DAMAGE

Pain is related to mechanical displacement of the middle ear system beyond its normal operational limits and the threshold for pain is reasonably established [50, 51, 55]. The threshold appears to be about 140 dB around 20 Hz increasing to about 162 dB at 2 Hz and to 175–180 dB for static pressure.

Tonndorf [44] was one of the first to report damage, in this case scarring of the tympanic membrane of German submariners, due to high level infrasound. A vascular infection of the eardrum membrane can also be observed during and following exposure [51].

3.4. MIDDLE EAR PRESSURE BUILD-UP

One of the most consistent findings, among reported effects of infrasonic and low frequency noise exposure, has been a pressure sensation in the middle ear. This effect begins to occur for levels of infrasound between 127–133 dB and does not necessarily become more intense as the sound pressure level is raised [45, 51, 56–58]. The sensation has been temporarily relieved by valsalva, but has persisted for some time after exposure in many subjects. This phenomenon may in fact be a side benefit of infrasound as a pressure build-up in the middle ear should reduce the transmission of audio sound and thus act as a set of earplugs.

3.5. HEARING PROTECTION

Effective hearing protection is highly desirable when exposure to high level low frequency noise occurs. Earmuff performance is generally reduced with decreased frequency and may even amplify the noise under the muff, whereas earplugs tend to perform well at low frequencies. For optimum protection, good imperforate insert earplugs are recommended for shorter exposures while for longer exposures the addition of earmuffs is recommended [3, 51, 55, 59].

3.6. COMMUNICATION EFFECT AND MASKING

High intensity low frequency noise has been found to influence various organisms and functions involved in speech production and such effects as voice modulation, gag sensations and chest wall vibrations have been reported [45, 56, 58, 60, 61]. Experiments have shown that low frequency sound masks higher frequency sound and to a greater extent than the reverse [62–64], while speech intelligibility is not affected until the masking level of the low frequency components is of the order of 115 dB *OASPL* [65, 66]. One recent study also showed that a masking effect was produced on the lower audiometric frequencies (125, 250, 500 and 1000 Hz) by low frequency tones (10, 12 and 16 Hz) when the loudness level was 81 phons, but not when the level was 70·5 phons [53]. Thus it appears that the masking and communication effect of low frequency noise is not of great significance unless very high levels exist.

3.7. PITCH DISCRIMINATION

An attempt was made recently at Chelsea College by Usher [67] to measure pitch difference limens (DLs) in the range 25–125 Hz using a two-alternative forced choice procedure which required the response alternatives UP and DOWN. Measurements were made in this way at five reference frequencies for four normal-hearing subjects of widely differing ages and amounts of musical experience. The results indicate that the DL is approximately constant in the range 63–125 Hz. However, as the frequency is reduced below 63 Hz, the DL appears to increase so that at 25 Hz its value is about three times its value at 63 Hz.

3.8. LIMITING LEVELS

A tentative limiting level for infrasound which applies for discrete frequencies or octave bands centred about the stated frequencies, was first proposed by Nixon [50] for 8-min

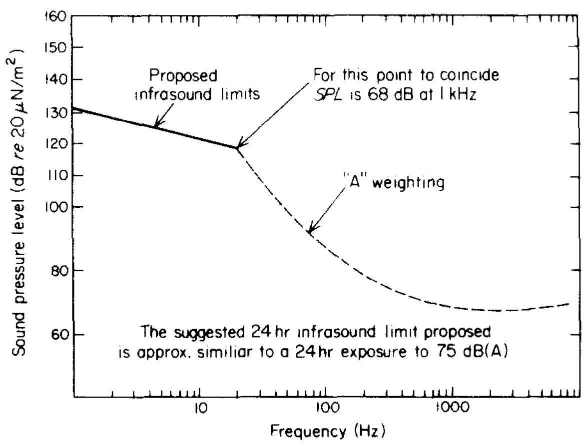


Figure 4. Suggested 24 hour exposure limits for infrasound (after Nixon [50]).

exposures and the equivalent 24-h exposure limit is shown in Figure 4. For computational purposes, an equal risk formula has been derived for level as a function of frequency and time, and limiting values so derived have been tabulated by Nixon and Johnson [51].

4. EQUILIBRIUM

The effect of low frequency noise on man's vestibular system has been mainly studied by means of direct nystagmus measurements (nystagmus is an indication of balance disturbance). Of the few studies employing the rail task, that of Hood, Leventhall and Kyriakides [68] found only two out of seven subjects affected at a level of 110–120 dB, while Johnson [61] found no effect at levels up to 140 dB and Nixon [69] found an effect at 150 dB.†

The nystagmus studies have also yielded differing results. Some have reported the presence of vertical nystagmus [70–72] while others have reported the absence of nystagmus [57, 61, 65, 73–75]. Brüel and Oleson [14] reported that they were able to produce "dizziness" even in sceptical subjects at a level of 95 dB (2 Hz, 2 h) but many psychological effects in their study reduce the reliability of their results. Recently, the earlier work purporting to show nystagmus directly elicited by infrasound was criticized by Harris, Sommer and Johnson [76, 77] mainly on two grounds. Firstly, they claimed that nystagmus was subject to many artifacts of measurement and that there are numerous types of nystagmus not vestibular in origin. Secondly, most of the earlier studies showing a nystagmus effect were criticized for being "weak in experimental methodology and in scientific reporting". Further, Johnson [31] himself claimed that he had stood on one leg with his eyes closed listening to 165 dB at 7 Hz and 172 dB at 1–8 Hz (frequency sweep) without effect, though this test was of very short duration.

It appears then that the level at which infrasound becomes a hazard to man with regard to balance and nystagmus effects in the sense that they contribute to significant changes on performance is still not known, but the level is probably at least above 130 dB except for more susceptible people for whom the level may be as low as 95 dB. The preliminary exposure limits proposed by Johnson [31, 61], shown in Figure 2, should therefore remain adequate, but it should be remembered that, whatever the case, equivalent levels of noise in the 20–100 Hz frequency range will be of much more consequence.

5. LOW FREQUENCY NOISE AND VIBRATION

There has been some suggestion that body response to acoustic excitation becomes progressively similar to that due to mechanical vibration as the excitation frequency reduces into the infrasonic region [78–80]. When a sound wave is large compared to body dimensions, as it is for low frequencies, the result is uniform compressional excitation which results in greater stiffness than unidirectional vibration excitation and thus higher resonant frequencies are excited [31, 57]. This result has been confirmed by experiment [81, 82] and can be interpreted in terms of the model of the human body developed by Von Gierke [83] and by means of an analogy with the basic mass-spring oscillator [33, 84].

Thus the action of low frequency noise on the body is different from that of vibration, though they are similar in their ability to excite resonances. However, the transmissibility of vibration to man is often greater than unity, while in contrast, there is very little absorption of acoustic energy by man (2% at 100 Hz, for example) due to the impedance mismatch between the airborne acoustical energy and the body [57, 85]. Consequently, very high levels of noise are required to get the same order of magnitude of response as from vibration, and for infrasound at least 130 dB would be required to produce effects that could begin to be a cause for concern [86].

† These apparently differing results can be possibly explained in terms of slight variations in experimental techniques.

6. THERAPEUTIC VALUE OF LOW FREQUENCY NOISE

There have been some suggestions that exposure to low frequency noise could be beneficial in some cases. For example, Johnston [55] quotes one study in which blasts of high intensity sound (frequency unstated) have been used to help produce ovulation in women with sex gland deficiencies and goes on to state that "It is for consideration that the womb, or other bodily organs, may be stimulated by suitable infrasonic frequencies to produce beneficial results". Johnston [55] also mentions that electrical stimulation of the brain at a frequency of 42·5 Hz has been shown to rectify colour blindness and thus "If infrasound can produce electrical signals of a suitable type in the brain, it might be possible to affect colour vision". Finally, Johnston [55] quotes one case where an experimenter exposed to a high intensity (155 dB) whistle at 340 Hz recovered the sense of smell that he had lost some years previously suggesting that "this appeared due to intense vibration of the nasal cavities" and "again, infrasonic induced resonances might possibly be used for therapeutic purposes". All these suggestions sound attractive, but appear to be based on single incidences of exposure to high intensity noise for which such effects could conceivably occur given the appropriate physical and environmental conditions.

Evans, Bryan and Tempest [71] suggested the use of low frequency sound for inner-ear investigations. They felt that this method would possibly possess several advantages over the two tests in common use, the Hallpike caloric and the rotating chair. Evans and Tempest [87] reported a euphoric feeling induced in some subjects by relatively low levels of infrasound (115–120 dB) which could possibly be used to relax people but it seems that their results applied to sensitive people and would therefore not be applicable to the general population. Finally Johnson [61] foresaw the possibility of using infrasound below 1 Hz to ventilate the lungs but the levels that would be required for this desirable effect (166 dB) are well above those that are acceptable from other points of view.

Therefore, it appears that infrasound does not have any practical application as a useful medical aid, but it is possible that noise within the 20–100 Hz range may find some benefit in the future.

7. BRAIN STIMULATION BY LOW FREQUENCY NOISE

A number of assertions have been made in the past, mainly in popular magazines, indicating that infrasonic stimulation synchronized with the subject's alpha waves (7 Hz is the median frequency of the alpha rhythm) could be a source of concern. Johnston [55] quotes the suggestion that such infrasound could either enhance intellectual capacity or trigger insanity in very unstable personalities while other reports suggest that such stimulation may be dangerous [80] or may cause a throbbing in the head making an intellectual task impossible. A much more dubious claim, that low frequency noise could cause brain tumours, has also been made [88–90]. In this case, the offending frequency was 37·3 Hz which was said to have caused the brain damage by stimulating or catalyzing accelerated growth of an originally dormant tumour. It must be strongly emphasized, however, that none of these claims have a basis in real research and are at this time purely speculative.

8. ENTERTAINMENT VALUE

Various claims have been made, often poorly substantiated, regarding the effect of low frequency sound in the entertainment world. The main effect, though, appears to be that of body resonance which could be a welcome effect at discotheques and pop concerts and can occur at levels below 100 dB [33, 82, 91]. Universal Pictures, Hollywood, specially developed their "*Sensurround*" system for the film "Earthquake" to simulate earthquake rumbles and vibrations and to be of such intensity as to be physically felt in the body as well as the head, but not dangerous [92–96]. This system appears to have been very successful and is being used in other films. Thus it seems that low frequency sound has a limited potential in the entertainment world and will probably be used in future to generate desired entertainment effects.

9. MILITARY USE OF LOW FREQUENCY NOISE

The first military use of low frequency noise was for the detection of enemy guns in World War One [79] and some reports indicate that during World War Two, the British and Japanese were investigating the use of low frequency noise as a weapon [55]. Gavreau [4] noted the possible military applications of infrasound. But if infrasound were to be used as a lethal weapon extremely high levels would be required. For example, it is known that lung rupture occurs at 10 kN/m^2 for a ramp-type compressive pressure change and while infrasound from an artificial source would not have a ramp-type change, it could nevertheless be assumed that to achieve a fatal injury, a level of at least 174 dB *SPL* (approximately 6 kN/m^2) would be required. Such a weapon would have to be suitable for use in a "stand-off" capacity, and a minimum range of say 250 m would be essential and 1000 m desirable. If one assumes the normal acoustical equations to determine the sound power required to generate 174 dB sound pressure at a distance of even only 250 m, then for a non-directional source (which this device would be) one has $PWL = SPL + 20\log_{10} r + 10{\cdot}8\,\mathrm{dB}$ giving $10\log_{10}(W/W_{\mathrm{ref}}) = 174 + 48 + 10{\cdot}8 \approx 233\,\mathrm{dB}$, so that $W = 2 \times 10^{11}$ watts. Thus, the sound power required even for an ideal system at 250 m is of the order of a thousand times that generated by a Saturn V rocket on lift-off. A further problem with such a device would be the large source size required. Bryan and Tempest [6] have calculated that the source would have to be 1100 m in diameter to have good directional properties for the radiation. Thus, a lethal infrasonic weapon appears unlikely, and such reports as the one which suggested that a sound gun had been developed but had proved unusable as it "would have killed everything within four miles" [97, 98] therefore seem to be fantasy.

With regard to the use of infrasound as a non-lethal weapon, a number of suggestions have been raised. These include its use for reducing resistance to interrogation, for inducing stress in an enemy force, for creating an infrasonic sound barrier and for rapid demolition of enemy structures [55]. One popular magazine in fact reported that infrasound was being utilized in Northern Ireland as a riot-control and non-violent crowd dispersal weapon [99]. But here again it must be pointed out that there is no valid research basis for these claims and that the power required to obtain these effects outside the laboratory is beyond present capabilities, especially if a portable device is required. It seems therefore, that military use of infrasound is not practical, and that the report [100] which suggested that "The *Trompette Marseillaise* with which Gavreau thought that he could re-enact the feat of Joshua before the walls of Jericho is only a beginning" was wishful thinking. However, the use of audio-frequency noise at high levels would seem to more practical, and it seems that white noise was in fact at one time used in Northern Ireland as a method of sensory deprivation.

10. NEWSPAPER SPECULATION

Over the last few years, the popular press has given the effects of low frequency, and in particular infrasonic noise, a great deal of sensational publicity, thus propagating the myths associated with these to the extent that they are believed by many. For example, such reports have appeared in the *Pharmaceutical Journal* [100] the *London Evening News* [17, 23] and the *Melbourne Sunday Press* [101] (see Figure 5). Very recently, a more serious report on low

THE LOW-PITCHED KILLER

From
Bruce Sandham in London

A FEW weeks ago a family car, being driven quite normally along Britain's M.5 motorway, suddenly wandered across the road, over the central reservation, and into the high-speed lane of the other carriageway.

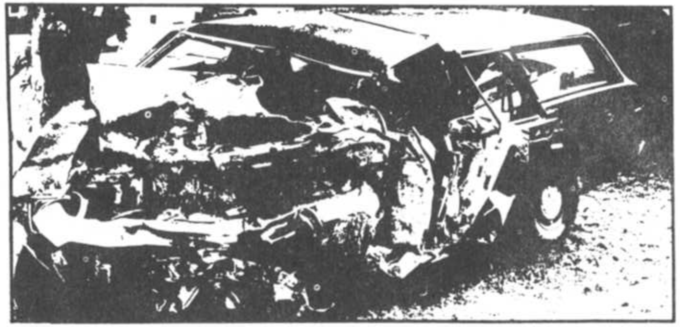
Within seconds, the inevitable happened. In the crash, which wrote off three vehicles, the driver of the family car was killed and four other people gravely injured.

The road was dry, the conditions perfect, and, according to a survivor, the car was doing under 60 mph. Yet, inexplicably, the driver suddenly behaved as though he had taken leave of his senses.

In fact that could well be what actually happened. Experts are already suspecting that the driver could be the latest victim of a road hazard most of us don't even know exists.

It's called infrasound — the noise below the range of human hearing which, when generated by a moving vehicle, can, in certain circumstances, make a driver behave as though he were drunk.

It can make us tired, dizzy, reckless, and possibly disturb the balance mechanism of the ears.



Can sounds of silence be driving us silly?

SCIENCE HINTS

Serious research into infrasound has only just begun. But already medical science is hinting that hundreds of accidents previously attributed to other causes might well have been due to the "silent sound" that can slow a driver's reactions by as much as 30 per cent.

Traditionally, load shrill noises have been regarded as the most dangerous: a blaring motor-horn sounded from six feet away can cut immediate visual reaction by 25 per cent.

But infrasound — noise with a frequency of below 30 cycles a second — is far harder to trace and often more lethal.

Now medical science is making a determined effort to understand, and if possible to nullify, the dangers of the sounds we can't hear.

The British Acoustical Society has already held a conference on the subject to alert members of the perils of infrasound generated by cars, trains, planes, and even oil-fired boilers.

In France, the French National Centre for Scientific Research has set up a special infrasound research laboratory in Marseilles to study the risks associated with infrasound and find whether any practical use can be made of it.

Among the devices they have installed are a huge whistle, four feet in diameter, which produces an ultra-low, scarcely-audible sound.

Functioning at full power it would still be virtually silent ... but would knock down buildings and kill anyone standing within 100 yards of it!

To study the effects on the human body of infrasound at ultra-low frequencies, French scientists have built an enormous "organ pipe" nearly 80 feet long, which produces sound at $3\frac{1}{2}$ cycles per second.

This is inaudible to the ear, but produces a fluttering sensation which distorts other sounds we hear. It can also cause dizziness and fatigue.

"Such sound abounds in industrial cities," says a Marseilles scientist.

It is generated by many kinds of machines and motors which turn at a slow rate.

"Even infrasound of weak intensity can penetrate houses and affect the occupants. The lower the sound is pitched the further it carries and the longer it lasts."

To investigate the long range effects, "acoustic beacons" are being used to project long-range beams of sound with great precision over distances of up to ten miles. These are then "caught" and examined by an instrument called an oscilloscope.

Already it has been found that infrasound can cause dizziness and discomfort to plane passengers, although, unlike other forms of plane noise, it has no effect on people on the ground.

But it is on the road that it appears to cause the most danger. Research at Britain's Salford University has shown that cars travelling at motorway speeds can produce about 100 decibels of infrasound with the windows shut, and up to 120 with them open.

That's only ten decibels less than the din of a riveting hammer!

AFFECTS EARS

Most of the sounds can be felt rather than heard, but the levels are perilously near those known to affect the ear's delicate balance mechanism — hardly the best thing to happen when you're driving at speed.

Most countries don't allow cars to produce more than 85 decibels of noise — but these are on frequencies which the ear can easily hear. There is virtually no legislation concerning infrasound.

Yet infrasound can do some spectacular things. Research at the Max Planck Institute in Dortmund, Germany, has shown that it can cause temporary changes in the blood circulation system, affect the digestion, and even bring about absent-mindedness.

Even more ominous is the story of the metal bucket left by accident in a room used for measuring the infrasound produced by jet engines. Within a month it had completely disintegrated.

If it does that to metal, what must it do to the human skull..?

Figure 5. Typical sensational newspaper report on infrasound (*Melbourne Sunday Press*, 7 September 1975). Reproduced by permission of Reuters Limited.

frequency noise drew over 800 letters of response from people complaining that they suffered from low frequency "hum" [24–26]. The speculation mainly began following the publication by Gavreau, Condat and Saul [3] and Gavreau [4] of certain statements, one of which, for example, was that infrasound was "certainly one of the many causes of allergies, nervous breakdowns and other 'unpleasant phenomena of modern life' found in industrial cities", which the authors made without having any scientific basis. Their report that a colleague was made an invalid for life following exposure to a Levavasseur whistle is understandable in view of the extremely high output of 1 kW which occurred at 2600 Hz. It appears though, that the person concerned may have already been suffering from a form of Parkinson's disease which may have been exacerbated somewhat by the exposure to this intense acoustic noise [102].

The painful irritation reportedly experienced by Gavreau and Saul after exposure to their "acoustic gun" is also not particularly surprising upon considering that it was operated at 196 Hz and 160 dB. Even so, shortly after, the U.S. *Miami Herald* headlined a popular article on Gavreau's work as "Sound Ray Developed as a Killer—French Working on War Machine" [55] and the London *Observer* (7 January 1968) also carried an article on "Sound as a Weapon of War" which suggested that infrasound might lead to a family of "exceedingly unpleasant new weapons".

Infrasound was next highlighted in a popular article headlined "Does Infrasound Make Drivers Drunk"? Shortly afterwards a controversy was aroused in the British press when Dickinson suggested that low frequency noise might be responsible for mental disturbances, "tummy" upsets and even brain tumours and cot deaths [88, 89]. Thus, the cause for a variety of ailments, for which no other satisfactory explanation could be given, was being attributed to infrasound based solely on circumstantial evidence and in spite of the fact that no valid scientific basis for such assertions existed. It has now been suggested, for example, that cot deaths may in fact be related to excess salt intake [103] and that a euphoric feeling induced during driving may be due to an excessive build-up of stress hormones [104]. The problem is thus that the press has been selective in their handling of low frequency and infrasonic noise effects in order to gain a "sensationalistic scoop" and has, in general, chosen to ignore the wide body of research which puts especially infrasonic effects in perspective. The fact is that effects due to infrasound at the levels at which it normally occurs or even at the levels at which it can be generated, are not nearly as consequential as similarly high levels of noise at 20 Hz and above.

11. PHYSIOLOGICAL EFFECT OF LOW FREQUENCY NOISE

Physiological responses have been observed or discussed by many investigators of the effects of low frequency noise on man [18, 31, 32, 45, 47, 56, 60, 61, 75, 87, 105–113]. These responses have included cardiac rhythm and respiration rate (measured by EKG recordings, pulse counts and impedance pneumography), change of systolic rhythm, blood and endocrine changes, and disturbances to the central nervous systems, as well as subjective responses.

It is now well known that low frequency noise can produce unpleasant subjective effects in some people, including such effects as nausea and feelings of panic or euphoria. However, extreme symptoms of these types are, in general, associated only with high levels of low frequency noise and very high levels of infrasound (a rough guide as to the limits for any significant physiological effects is given in Figure 2). The more subtle physiological effects generally do not seem to be of great significance.

12. EFFECTS OF LOW FREQUENCY NOISE ON HUMAN PERFORMANCE

The first major studies of low frequency noise effects on human performance were concerned with the possible effects of noise generated by aerospace systems such as the Saturn V rocket on spacecraft occupants during launch and orbital insertion [45–48, 56, 105]. These led to the conclusion that for short exposures (up to 3 min) the low frequency environments could be tolerated with little or no degradation of performance (see Table 1). The results reported by Gavreau, Condat and Saul [3] and Gavreau [4], though, were quite startling in that they suggested that infrasound could cause some serious effects at relatively low levels. Although somewhat speculatively, Green and Dunn [114] in a longer term correlational study, suggested that the presence of infrasonic disturbances due to storms in Chicago were correlated to a degree with changes in selected human behaviour (automobile accident rate and absenteeism of school children).

TABLE 1

Low frequency noise effects observed by Mohr et al. [45]

Exposure	Tolerance data Observed behaviour
0 to 50 Hz Up to 145 dB	Chest wall vibration, gag sensations, respiratory rhythm changes, post-exposure fatigue; voluntary tolerance not exceeded
50 to 100 Hz Up to 154 dB	Headache, choking, coughing, visual blurring and fatigue; voluntary tolerance limit reached
Discrete frequencies	Tolerance limit symptoms
100 Hz at 153 dB	Mild nausea, giddiness, sub-costal discomfort, cutaneous flushing
60 Hz at 154 dB 73 Hz at 150 dB	Coughing, severe substernal pressure choking respiration, salivation, pain on swallowing, giddiness

Since then, a number of studies have been carried out (with various tasks utilized to investigate reaction time, visual acuity, vigilance and cognitive functions and other motor functions), some of which produced results in support of the contention that infrasound causes performance effects, with others in opposition to it. Hood, Leventhall and Kyriakides [68], Evans and Tempest [87], Bryan and Tempest [6], Leventhall [84], Hood [115], Brüel and Oleson [14], Kyriakides [116], Benignus *et al.* [117] and Kyriakides and Leventhall [118] all noted some degree of performance degradation in selected tasks due to infrasound (a level of only 80 dB was used in one case). Leventhall [84] also noted that while adverse effects occurred at lower levels, an improvement in performance sometimes occurred at higher levels thereby suggesting an *arousal* effect similar to that reported widely for high frequency noise. Poulton and Edwards [119] also noted such an arousal effect for "green noise" of 102 dB(C) *OASPL* and suggested that a situation in which low frequency noise improves performance while white noise degrades it may be due to the masking of important auditory cues by the more intense high frequencies of the white noise. They noted, however, that the low frequency noise must not be too loud (greater than 118 dB(C) *OASPL*) (see also [120]). Smith *et al.* [52], however, exposed groups of men for a 24 h period to a 70 Hz tone at 122·8 ± 10 dB and measured performance on a sensory-motor task periodically. No decrement in the "RATER" performance task was noted.

Recently, Harris, Sommer and Johnson [76, 77] criticized these earlier claims that infrasound adversely affected human performance and stated that the effects obtained at low intensity levels (105–120 dB), if they could be substantiated at all, have been exaggerated. This view is supported by the early research work of 1965 and 1966 mentioned previously, as well as the later work of Borredon [110], Borredon and Nathie [111], Johnson [61], Von Gierke [57] and Slarve and Johnson [58, 109] which indicated that no significant effects due to infrasound below at least 130 dB would occur. It should be noted, though, that these studies (except for those of Borredon [110] and Borredon and Nathie [111]) were all of short duration (8 min maximum) exposure while in those by Hood, Leventhall and Kyriakides [68], Leventhall [84], Hood [115], Brüel and Oleson [14], Poulton and Edwards [119] and Kyriakides [116], all of which indicated at least a tendency towards a performance decrement, exposures of 30 min or more were used. Recent unpublished data obtained at Chelsea College for a three hour exposure to low frequency audio noise at 90 dB also indicate degradation in performance of a primary pointer-following task.

With regard to limiting levels, uncertainty is reflected by the fact that the levels indicated by Bryan and Tempest [6] (Figure 6) are more conservative than those of Stephens [121] (Figure 7) and those of Johnson [31] (Figure 2). (Even though Johnson does not actually suggest a limiting level for performance effects, it can still be suggested that at least the annoyance limiting levels are required for a performance effect to occur, if one remembers that there is not necessarily a positive correlation between annoyance and performance.) The difference, though, can be reconciled somewhat by noting a different emphasis. On the one hand the concern is with which minimum levels may cause an effect in any section of the population, while on the other hand, the approach seems to be concerned with what levels can be tolerated for short exposures. Furthermore, confusion arises in the vagueness of terms used. For example, what is really meant by "reaction time threshold" (Figure 6) or what is meant by "adverse" physiological effects (Figure 2). It would appear that the latter term is referring to physiological effects which may result in permanent damage while the former term is most likely referring to the levels at which even a minute non-statistically significant effect may occur in some sections of the population. Much of the data on infrasonic effects published to date lacks this type of definition or qualification, and there are also shortcomings in the experimental methodology of the work or in the scientific reporting of it.

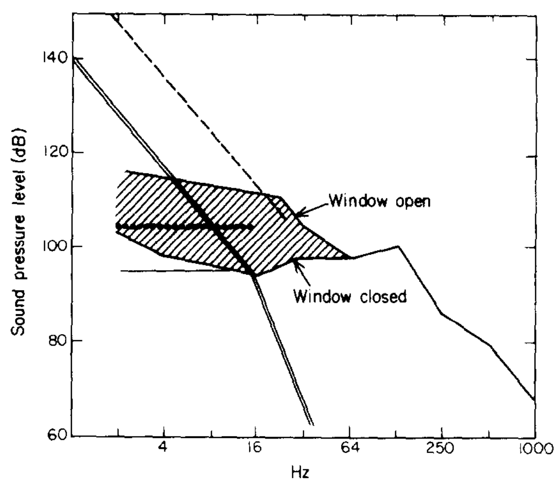


Figure 6. Threshold of infrasound levels affecting vigilance, reaction time and balance, suggested by Bryan and Tempest [6], and the hearing threshold. The heavy lines trace the noise levels inside a British one litre saloon car travelling at 60 mph. ——, Noise levels in car at speed; ----, threshold for balance disturbance; ══, hearing threshold; · · · ·, reaction time threshold; ——, threshold for effect on vigilance.

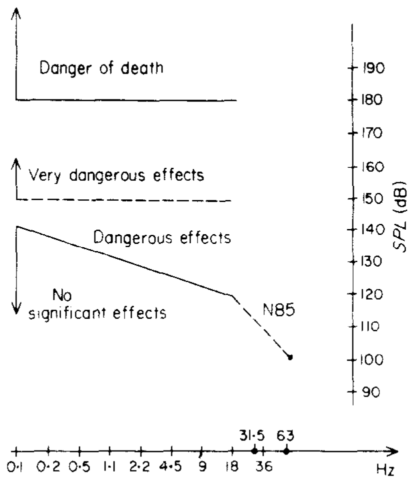


Figure 7. Limiting levels for infrasonic effects proposed by M. Stan (after Stephens [121]).

Whether performance is affected by infrasound is therefore still not entirely clear, but it appears that a statistically significant detrimental effect is likely to occur only on complex tasks after a long exposure, as is generally the case for audio-frequency noise. More research on performance effects due to long exposure is, therefore, required and work on this is currently in progress at Chelsea College, with 6 h exposures. However, it must be again emphasized that equivalent levels in the audio-frequency region are of much more consequence.

13. CONCLUSION

The review of low frequency noise effects indicates that the effects are similar to those of higher frequency noise, though to a different degree, and that the effects of infrasound, though comparable to those of audio frequency noise in a number of ways, have been much over-rated. It is also apparent that the high level low frequency noise in the 20–100 Hz range is of much more significance than infrasound at the same level in most environments where low frequency noise is a problem.

Another point is that, as Harris, Sommer and Johnson [76] have stated, "there are good reasons for questioning the conclusions contained in most studies on the effects of infrasound on man. Most studies are weak in experimental methodology and the scientific reporting". Furthermore, as they warned, "Caution is necessary in future research because artifacts produced by faulty experimental procedures can suggest genuine psychological or physiological effects". Thus, there is the need for future research papers to describe fully the experimental procedures and the statistical methods used, and to also avoid the use of vague or ambiguous terminology as has occurred in the past.

A summary of various infrasonic threshold levels where different effects may occur can nevertheless be indicated as in Table 2, although the limits depicted in Figure 2 are probably more useful. On the basis of existing data, it therefore seems that the threshold for infrasonic effects is approximately 120 dB sound pressure level. However, as little information exists with respect to longer duration exposures, care should be taken in interpreting the results. It must be pointed out again, though, that high level infrasound is usually accompanied by high level low frequency noise, and in perspective it is the low frequency noise (20–100 Hz) that one should be most concerned with, whether for short- or long-term exposures.

TABLE 2

Summary of minimum threshold levels for infrasonic effects due to short-term exposures (adapted from Johnson [31, 61])

Effect	Threshold level (dB)
Whole-body	>140
Respiration	>166
Vestibular	>130
Auditory	>130
Performance	>120–130
Physiological	>120–130
Annoyance	>55 $L_{DN}, f > 5$ Hz >120 $L_{DN}, f < 5$ Hz

With regard to low frequency noise in the 20–100 Hz range, however, not much data is available in the form of limiting levels. At this stage it is too early to speculate about the level at which no adverse physiological effects will occur. But it should be noted that for high frequency noise, the level identified as requisite to protect the public from hearing loss with an adequate margin of safety is $L_{eq}(24) = 70$ dB [34].

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REFERENCES

1. N. BRONER 1976 *Proceedings of the Vibration and Noise Control Engineering Conference, Institution of Engineers, Australia, Sydney, October*, 56–60. Low frequency noise and testing for it's effects.
2. N. BRONER 1978 *Applied Acoustics* **11**, 129–146. Low frequency and infrasonic noise in transportation.
3. V. GAVREAU, R. CONDAT and H. SAUL 1966 *Acustica* **17**, 1–10. Infrasons: generateurs, detecteurs, propriétés physiques, effets biologiques.
4. V. GAVREAU 1968 (January) *Science Journal* **1**, 33–37. Infrasound.
5. M. E. BRYAN 1971 *Proceedings of the Autumn Meeting of the British Acoustical Society, November* 71–109. Annoyance effects due to low frequency sound.
6. M. E. BRYAN and W. TEMPEST 1972 *New Scientist* **53**, 584–586. Does infrasound make drivers drunk?
7. S. MULLIN 1972 *New Scientist* **53**, 709. Infrasound's effects.
8. J. G. BIRNEY 1972 *New Scientist* **54**, 101. Infrasound.
9. ANON 1973 (September) *Noise and Vibration Bulletin*, 239. Supermarket.
10. C. O. LEIBER 1974 *Institut für Chemisch-technische Untersuchungen (CTI), Bonn, June*. Physiologische Auswirkungen des Infraschalls (Eine Befragung).
11. ANON 1973 (March) *Noise and Vibration Bulletin* 84. The infrasonic bus.
12. ANON 1973 (November) *Noise and Vibration Bulletin* 286. Oil-fired boiler.
13. N. NISHIWAKI and T. MORI 1976 *Internoise* 76, *No.* 31. Noise at infrasound frequencies generated by machines and methods for decreasing S.P.L.
14. P. V. BRÜEL and H. P. OLESON 1973 *Brüel and Kjaer Technical Review No.* 3, 14–25. Infrasonic measurements.
15. C. ASHLEY 1975 *Journal of Sound and Vibration* **43**, 465–466. Chairman's report on the workshop on infrasound.

16. N. Nishiwaki and T. Mori 1976 *Internoise* 76, *No.* 30. Infrasound, generated by oscillatory motion of a bridge in a freeway in Japan.
17. Anon 1975 (November) *Noise and Vibration Bulletin* 274. Infrasound.
18. C. O. Leiber 1976 *Acustica* **34**, 251–252. Zur Wirkung des Infraschalls auf Menschen.
19. J. Hanlon 1973 *New Scientist* **60**, 415–416. Can some people hear the jet stream?
20. Anon 1974 (February) *Noise and Vibration Bulletin* 37. Abnormally acute hearing.
21. Anon 1976 (August) *Noise and Vibration Bulletin* 217–218. Infrasound in Poole.
22. Anon 1976 (October) *Noise and Vibration Bulletin* 269–270. Hum.
23. Anon 1977 (April) *Noise and Vibration Bulletin* 98–99. Mystery noise.
24. Anon 1977 (19 June) *The Sunday Mirror* 19. Have you heard the hum?
25. Anon 1977 (26 June) *The Sunday Mirror*. Hounded by this nagging noise.
26. Anon 1977 (3 July) *The Sunday Mirror* 7. Hum—that mystery noise drives sobbing wife out of the house.
27. W. Tempest 1973 *Acustica* **29**, 205–209. Loudness and annoyance due to low frequency sound.
28. S. D. Kraemer 1973 *M.Sc. Dissertation, Chelsea College, London.* Annoyance of low frequency sounds.
29. R. N. Vasudevan and C. G. Gordon 1977 *Applied Acoustics* **10**, 57–69. Experimental study of annoyance due to low frequency environmental noise.
30. M. E. Bryan 1976 *Infrasound and Low Frequency Vibration* (W. Tempest, editor) 65–96. Low frequency annoyance. London: Academic Press.
31. D. L. Johnson 1975 *Inter-Noise* 75, *Sendai*, 475–482. Auditory and physiological effects of infrasound.
32. D. L. Johnson 1976 *Proceedings of Electro* 76, *Boston, May, Paper* 12–4. Infrasound, its sources and its effects on man.
33. H. G. Leventhall 1974 *8th International Congress of A.I.C.B., Basle, June.* The effects of low frequency noise on man.
34. Anon 1974 *U.S. E.P.A. Report* 550/9-74-004. Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety.
35. G. Bekesy 1960 in *Experiments in Hearing* (E. G. Wever, editor) 257–267. New York: McGraw-Hill.
36. J. F. Corso 1958 *American Journal of Psychology* **71**, 367–374. Absolute thresholds for tones of low frequency.
37. N. S. Yeowart, M. E. Bryan and W. Tempest 1967 *Journal of Sound and Vibration* **6**, 335–342. The monoaural M.A.P. threshold of hearing at frequencies from 1·5 to 100 c/s.
38. N. S. Yeowart, M. E. Bryan and W. Tempest 1969 *Journal of Sound and Vibration* **9**, 447–453. Low-frequency noise thresholds.
39. L. S. Whittle, S. J. Collins and D. W. Robinson 1972 *Journal of Sound and Vibration* 21, 431–448. The audibility of low-frequency sounds.
40. N. S. Yeowart and M. J. Evans 1974 *Journal of the Acoustical Society of America* **55**, 814–818. Thresholds of audibility for very low frequency pure tones.
41. B. W. Lawton 1975 *NASA TM X*-72649. The noisiness of low frequency bands of noise.
42. N. S. Yeowart 1971 *Proceedings of the Autumn Meeting of the British Acoustical Society November* 71–103. Low frequency threshold effects.
43. D. L. Johnson and H. E. Von Gierke 1974 *Presented at the Acoustical Society of America Fall Meeting, November.* The audibility of infrasound.
44. J. Tonndorf 1950 *Chapter DII, Appendix to German Aviation Medicine in World War II, Department of the Air Force.* The influence of service on submarines on the auditory organ.
45. G. C. Mohr, J. N. Cole, E. Guild and H. E. Von Gierke 1965 *Aerospace Medicine* **36**, 817–824. Effects of low frequency and infrasonic noise on man.
46. J. C. Guignard and R. R. A. Coles 1956 *5th International Congress on Acoustics, Liège, September Paper B*57. Effects of infrasonic vibration on the hearing.
47. B. R. Alford, J. F. Jerger, A. C. Coats, J. Billingham, B. O. French and R. O. McBrayer 1966 *Transactions of the American Academy of Opthalmology and Otolaryngology* **701**, 40–47. Human tolerance to low frequency sound.
48. B. O. French, R. O. McBrayer, W. E. Feddersen, G. J. Pesman and J. Billingham 1966 *NASA TN D*-3323. Effects of low frequency pressure fluctuations on human subjects.
49. J. Jerger, B. Alford, A. Coats and B. French 1966 *Journal of Speech and Hearing Research* **9**, 150–160. Effects of very low frequency tones on auditory thresholds.
50. C. W. Nixon 1973 *Proceedings of the Colloquium on Infrasound, Centre National de la Récherche Scientifique, Paris, September*, 315–336. Human auditory response to intense infrasound.

51. C. W. Nixon and D. L. Johnson 1973 *Proceedings of the International Congress on Noise as a Public Health Problem, Dubrovnik, May*, 329–347. Infrasound and Hearing.
52. P. F. Smith, M. S. Harris, J. S. Russotti and C. K. Myers 1970 *U.S. Naval Submarine Medical Center Report No.* 610. Effects of exposure to intense low frequency tones on hearing and performance.
53. N. Ramet 1975 *M.Sc. Dissertation, Chelsea College, University of London.* Low frequency effect on hearing.
54. Anon 1973 *U.S. E.P.A. Report* 550/9-73-002. Public health and welfare criteria for noise.
55. J. F. J. Johnston 1971 *Royal Military College of Science, England.* Infrasound—a short survey.
56. P. M. Edge and W. H. Mayes 1966 *NASA TN D*-3204. Description of Langley low frequency noise facility and study of human response to noise frequencies below 50 cps.
57. H. E. Von Gierke 1973 *Proceedings of the Colloquium on Infrasound, Centre National de la Récherche Scientifique, Paris, September*, 419–435. Effects of infrasound on man.
58. R. N. Slarve and D. L. Johnson 1974 *Preprint of the Aerospace Medical Association* 1974. *Annual Scientific Meeting, Washington D.C., May*, 129–130. Human whole body exposure to infrasound.
59. C. W. Nixon, H. K. Hille and L. K. Kettler 1967 *Aerospace Medicine Research Laboratory Technical Report No.* 67–27. Attenuation characteristics of earmuffs at low audio and infrasonic frequencies.
60. L. Pimonow 1971 *Revue d'Acoustique* **15**, 205–212. L'action physique et physiologique des infra-sons et des sons graves.
61. D. L. Johnson 1973 *Proceedings of the Colloquium on Infrasound, Centre National de la Récherche Scientifique, Paris, September*, 337–355. Various aspects of infrasound.
62. J. M. Pickett 1959 *Journal of the Acoustical Society of America* **31**, 1259. Low frequency noise and methods for calculating speech intelligibility.
63. A. Finck 1961 *Journal of the Acoustical Society of America* **33**, 1140–1141. Low frequency pure tone masking.
64. N. L. Carter and K. D. Kryter 1962 *Journal of Auditory Research* **2**, 66–98. Masking of pure tones and speech.
65. N. S. Yeowart 1973 *Proceedings of the Colloquium on Infrasound, Centre National de la Récherche Scientifique, Paris, September*, 289–306. The effect of infrasound on man.
66. N. S. Yeowart and P. E. Connor 1974 *Applied Acoustics* **7**, 229–231. The effect of infrasonic and very low frequency noise on speech intelligibility.
67. N. Usher 1977 *Acoustics Letters* **1**, 36–37. Pitch discrimination at low frequencies.
68. R. A. Hood, H. G. Leventhall and K. Kyriakides 1971 *Proceedings of the Autumn Meeting of the British Acoustical Society, November*, 71–107. Some subjective effects of infrasound.
69. C. W. Nixon 1966 *Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, AMRL-TR*-65-85. Rail test to evaluate equilibrium in low level wideband noise.
70. M. J. Evans 1971 *Proceedings of the Autumn Meeting of the British Acoustical Society, November*, 71–104. Infrasonic effects on the human organs of equilibrium.
71. M. J. Evans, M. E. Bryan and W. Tempest 1971 *Sound* **5**, 47–51. Clinical applications of low frequency sound.
72. M. J. Evans 1976 in *Infrasound and Low Frequency Vibration* (W. Tempest, editor) 97–113. Physiological and psychological effects of infrasound at moderate intensities. London: Academic Press.
73. D. E. Parker, M. F. Reschke and R. L. Tubbs 1973 *Presented at the Aerospace Medicine Panel Meeting of AGARD, Florida, May.* Effects of sound on the vestibular system.
74. C. S. Harris, H. C. Sommer and D. L. Johnson 1975 *Presented at the Aerospace Medicine Association Meeting, San Francisco.* Human equilibrium during exposure to infrasound.
75. H. E. von Gierke and C. W. Nixon 1976 in *Infrasound and Low Frequency Vibration* (W. Tempest, editor) 115–150. Effects of intense infrasound on man. London: Academic Press.
76. C. S. Harris, H. C. Sommer and D. L. Johnson 1974 *Aerospace Medical Research Laboratory, Wright Patterson Air Force Base, Ohio, AMRL-TR*-74-70. The effects of infrasound on man: is there a demon in our midst?
77. C. S. Harris, H. C. Sommer and D. L. Johnson 1976 *Aviation, Space and Environmental Medicine* **47**, 430–434. A review of the effects of infrasound on man.
78. J. C. Guignard 1967–68 *Proceedings of the Institution of Mechanical Engineers, London* **182**, 67–71. Human response to intense low frequency noise and vibration.
79. R. W. B. Stephens 1969 (January) *Ultrasonics* 30–35. Infrasonics.
80. R. W. B. Stephens 1971 *7th International Congress on Acoustics, Budapest.* Very low frequency vibrations and their mechanical and biological effects.

81. K. Kyriakides and H. G. Leventhall 1974 *8th International Congress on Acoustics, London.* Some subjective effects of infrasound.
82. H. G. Leventhall and K. Kyriakides 1974 *Presented at the Annual Conference of the U.K. Group on Human Response to Vibration, Yeovil, September.* Acoustically induced vibrations of the body.
83. H. E. Von Gierke 1968 *Annals of the New York Academy of Sciences* **152**, 172–186. Response of the body to mechanical forces—an overview.
84. H. G. Leventhall 1973 *Proceedings of the Colloquium on Infrasound, Centre National de la Récherche Scientifique, Paris, September*, 129–152. Man-made infrasound, its occurrence and some subjective effects.
85. J. B. Westin 1975 *Aviation, Space and Environmental Medicine* **46**, 1135–1140. Infrasound: a short review of effects on man.
86. D. L. Johnson 1974. Personal communication.
87. M. J. Evans and W. Tempest 1972 *Journal of Sound and Vibration* **22**, 19–24. Some effects of infrasonic noise in transportation.
88. J. Hanlon 1973 *New Scientist* **60**, 386–387. Unsound tactics.
89. Anon 1973 (October) *Noise and Vibration Bulletin* 261–262. Infrasound.
90. P. J. Dickinson 1974 Personal communication.
91. H. G. Leventhall 1973 (15 December) *The Lancet* 1368–1369. Infrasound.
92. Anon 1974 (30 November) *Billboard.* Cerwin-Vega assists with Earthquake.
93. Anon 1974 *New Scientist* **64**, 729. You'll feel it as well in Sensurround.
94. E. J. Czerwinski and G. R. Lewis 1975 (April) *Audio*, 46–52. Earthquake sound system.
95. N. Williams 1975 (April) *Electronics Australia*, 14–19. From a hi-fi ideal to a sonic earthquake.
96. W. Yentis 1975 (April) *Recording Engineer/Producer.* Earthquake's Sensurround.
97. Anon 1974 (June) *Noise and Vibration Bulletin*, 123–124. Infrasound.
98. L. Watson 1974 *Supernature.* London: Coronet Books.
99. Anon 1973 *New Scientist* **59**, 684. Army tests new riot weapon.
100. Anon 1974 (January) *Noise and Vibration Bulletin*, 20. Infrasound.
101. B. Sandham 1975 (7 September) *Melbourne Sunday Press.* The low-pitched killer—can sounds of silence be driving us silly?
102. H. Saul 1975 Personal communication.
103. Anon 1975 (20 September) *British Medical Journal*, 664. Risk of cot deaths.
104. Anon 1975 *A.A. Drive, New Year*, 70. High Road.
105. P. M. Edge and W. H. Mayes 1966 *Proceedings of the Conference on Langley Research Related to the Apollo Mission*, 179–188. Some initial results of low frequency noise research.
106. E. Z. Andreeva-Galanina 1970 *Gigiena I Sanitariya* **11**, 65–69. Effects of infrasound on the human system (in Russian). (Also 1971 (January) *Noise and Vibration Bulletin*, 3–6 (in English).)
107. R. Fecci, R. Barthelemy, J. Bourgoin, A. Mathias, H. Eberle, A. Moutel and G. Jullien 1971 *Medicina del Lavoro* **62**, 130–150. The effects of infrasound on the body.
108. L. Pimonow 1973 *Proceedings of the Colloquium on Infrasound, Centre National de la Récherche Scientifique, Paris, September*, 33–58. Apercu genéral du domaine infra-sonore.
109. R. N. Slarve and D. L. Johnson 1975 *Aviation, Space and Environmental Medicine* **46**, 428–431. Human whole-body exposure to infrasound.
110. P. Borredon 1972 *Centre de Récherches de Médecine Aeronatique Report* 3713. Réaction physiologiques des sujets humains exposés à des infrasons.
111. P. Borredon and J. Nathie 1973 *Proceedings of the Colloquium on Infrasound, Centre de la Récherche Scientifique, Paris, September*, 59–84. Effets physiologiques observés chez l'homme exposé à des niveaux infrasonores de 130 dB.
112. D. L. Johnson 1973 *Presented at the Aerospace Medicine Association Meeting.* Effects of infrasound on respiration.
113. W. Tempest and M. E. Bryan 1972 *Applied Acoustics* **5**, 133–139. Low frequency sound measurements in vehicles.
114. J. E. Green and F. Dunn 1968 *Journal of the Acoustical Society of America* **44**, 1456. Correlation of naturally occurring infrasonics and selected human behaviour.
115. R. A. Hood 1973 *Ph.D Thesis, Chelsea College, University of London.* The occurrence and some subjective effects of infrasonic noise.
116. K. Kyriakides 1974 *Ph.D. Thesis, Chelsea College, University of London.* A study of environmental infrasound and some effects of infrasound on task performance.
117. V. A. Benignus, D. A. Otto and J. H. Knelson 1975 *Perceptual and Motor Skills* **40**, 231–239. Effect of low frequency random noises on performance of a numeric monitoring task.

118. K. KYRIAKIDES and H. G. LEVENTHALL 1977 *Journal of Sound and Vibration* **50**, 369–388. Some effects of infrasound on task performance.
119. E. C. POULTON and R. S. EDWARDS 1974 *Journal of Experimental Psychology* **102**, 621–628. Interactions and range effects in experiments on pairs of stresses: mild heat and low frequency noise.
120. ANON 1974 *New Scientist* **63**, 574. Do your best work in a lorry cab.
121. R. W. B. STEPHENS 1973 *Proceedings of the Colloquium on Infrasound, Centre National de la Récherche Scientifique, Paris, September*, 411–413. Summary of round table meeting on Wednesday, 26 September 1973.