THE EFFECTS OF INFRASOUND ON HUMAN HEALTH

by

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Abstract

Infrasound is defined as sound with a frequency less than 20 Hz. It is produced by both natural and man-made sources, although very high levels of infrasound must be artificially produced. A number of early papers suggested that infrasound may produce very serious adverse effects on human functioning such as the impairment of task performance, including driving. This paper assesses the literature published since those early reports. Auditory, physiological, and performance effects are discussed. The more recent studies show much less severe effects than those suggested in the first studies. Methodological considerations indicate that the recent studies are much more reliable than the earliest reports.

Sommaire

Le son à des fréquences moins de 20 Hz est appelé infrason. Il peut être émis par des sources aussi bien naturelles qu'artificielles, mais à des niveaux très élevés il doit être d'origine artificielle. Quelques recherches antérieures ont indiqué que l'infrason peut provoquer des effets néfastes sur le fonctionnement de l'être humain, comme l'accomplissement d'une tâche, y inclus conduire un véhicule. Cet article fait la critique de la littérature publiée depuis ces recherches antérieures. Des effets auditifs, physiologiques et des effets sur l'accomplissement des tâches sont présentés. Des études récentes montrent que ces effets sont moins sévères que l'indiquaient les premières recherches. En plus, des considérations méthodologiques prouvent que les résultats des études récentes sont plus exacts que ceux des recherches antérieures.

Introduction

The effects of infrasound on human health became a cause of concern during the mid 1960's when astronauts involved in the U.S. space program were found to be exposed to high levels of infrasound (in excess of 150 dB) for short periods during launch. Much of the work examining the effects of infrasound was done in response to this concern. However, infrasound is found in everyday life as well, most commonly in motor vehicles (especially trucks). In this context, infrasound is a concern because it penetrates walls and barriers with less attenuation than higher frequency sound.

Infrasound is defined as sound of a frequency less than 20 Hz. This definition was accepted at the International Colloquium on Infrasound in Paris in 1973, and has been commonly used since that time. Naturally occurring infrasound (thunderstorms, etc.) is usually in the frequency range below 2 Hz, while infrasound due to manmade sources is normally above this frequency. Levels of infrasound between 75 and 95 dB are common, while levels up to 120 dB may be produced in motor vehicles. Higher levels of infrasound must be artificially produced. These figures may be compared to a threshold of perception of 90 dB at 20 Hz. As is suggested by the threshold of perception, infrasound is not in fact inaudible, as is commonly believed. The higher frequencies in the infrasound range are audible, although it is not the pure tones which are heard, but rather harmonics generated by distortion from the middle and inner ear.

Many of the early papers which examined the effects of infrasound were alarmist, causing a great deal of excitement about possible effects. For instance, Gavreau (1968) warned of "profound effects on both men and buildings". Bryan and Tempest (1972) gained considerable newspaper publicity for their paper entitled "Does Infrasound Make Drivers Drunk?" They claimed that infrasound in motor vehicles could be the cause of many unexplained highway accidents. Close examination of these papers reveals that there is little or no scientifically derived data to support these claims. The publicity accorded these papers has had the effect of predisposing many people to believe that infrasound must have a deleterious effect, and to some extent this has hindered an accurate assessment of how hazardous it really is.

A number of papers, however, are designed to measure the health effects of infrasound using accepted scientific methods. A literature search using computerized bibliographies was conducted to find all papers relating infrasound to human health. After deleting those papers which used animal subjects, and those which were not in English (due to the limited budget for this effort, precluding translation), 19 papers remained: 7 reporting original research, and 12 review papers. These 19 form the basis for this study. The papers dealt with three aspects of health: auditory, physiological, and performance effects.

Each paper was examined to identify what information it contributes to the body of knowledge concerning infrasound and human health. In addition, each paper which contains original research was subjected to a critical appraisal designed to assess the validity of its conclusions, based on the strength of the analytical techniques used, and possible biases or confounders in the design or analysis.

This paper has three sections. The first describes the criteria used to evaluate the literature. The next assesses the literature on the effects of infrasound, on the basis of those criteria. The final section reports our conclusions.

Assessment Criteria

In other reports (Taylor et al., 1980) we have used both methodological and epidemiological criteria to assess the evidence that noise causes health problems. For infrasound, however, there are too few empirical studies to warrant using the epidemiological criteria for causation (see Sackett, 1976). Most of the methodological criteria can be applied, and provide a valuable framework for judging how much is really known about the effects of infrasound. The seven criteria used for the present study are as follows.

1. Is the problem statement clear?
2. What is the sample size?
3. How was the exposure measured, and what is the level and duration of exposure?
4. Is the outcome considered a health outcome or a physiological change?
5. Is the outcome measurement objective or subjective? Were the measurements taken in a vigorous manner?
6. Was any statistical analysis performed, and are the statistics appropriate?
7. Are there any confounding factors which will interfere with the direct relationship between exposure and outcome, or any biases in the way the sample was selected?

No matter how good each study might be individually, when judged on these criteria the overall generalizability of the results must necessarily be limited because of the limited number and scope of the studies. In order to present infrasound as the only noise source, most of the work on the effects of infrasound is conducted in a laboratory with an artificial noise source. The length of exposure to infrasound during the experiments is quite short. Also, the number of subjects in each experiment is small. Further, because the literature was largely a response to a particular exposure problem, the findings may not be applicable to some critical issues. For instance, there are no studies which directly examine the effects of infrasound from transportation sources on health, because infrasound here occurs only in combination with higher frequency sound. In addition, the existing studies are an inadequate indicator of the possible effects of exposure to low level infrasound over long periods of time, such as in an industrial setting.

Assessment of Studies

For the seven papers reporting original research, summaries in terms of the assessment criteria are given in Table 1. The dominant impression from the table is of very small samples (only one study has more than 30 subjects), and, perhaps as a consequence, an absence of statistical tests of results. For simplicity of presentation the papers will be discussed under three headings: auditory; physiological; and performance effects.

1. Auditory Effects. Three papers discuss the auditory effects of infrasound. All of the papers used temporary threshold shift as the outcome

measure; no paper examined the possibility of permanent threshold shift. Jerger et al (1966) exposed 19 subjects to infrasound levels up to 144 dB for three minutes (ear only exposures). 8 of the subjects showed no TTS, while the remainder exhibited TTS of 10-22 dB in the 3-8 kHz range. All of the subjects experienced full recovery, and there was no accumulation of TTS during successive exposures.

Mohr et al. (1965), as part of an experiment designed to study various effects of noise at frequencies between 1 and 100 Hz, exposed 5 subjects to infrasound at levels up to 150 dB for a minimum of 2 minutes (6 different frequency ranges). Some of the experiments were conducted using hearing protectors, although those tests are not identified. The authors provide only a summary of their findings but say that they found no statistically significant objective effect of infrasound. They state that no shifts in hearing threshold were detectable one hour after exposure. It should be noted here that the authors utilized only noise experienced personnel (Air Force officers) in the tests, which may be a source of bias.

One review paper also contributes additional data about the effect of infrasound on temporary threshold shift. von Gierke (in Tempest, 1976, chapter 6) reports on Johnson's work presented at the International Colloquium in Paris. The work involved two parts; whole body exposure and ear only exposure. The subjects for the whole body exposure experiment were exposed to the same levels as those of Jerger et al (120-144 dB), but for 8 minutes. There was no effect on TTS for this exposure. In the ear only exposures, the subjects were exposed to higher levels of infrasound (up to 171 dB) for periods ranging from 26 seconds to 30 minutes. Temporary threshold shift of 8 dB was measured after exposure to 140 dB for 5 minutes, and of 14-17 dB after 30 minutes exposure to the same level. All subjects recovered fully within 30 minutes after exposure.

The studies examining the auditory effects of infrasound all agree that exposures of relatively short duration result only in temporary threshold shift, which disappears within 30-60 minutes after exposure. Levels of approximately 140 dB were necessary to produce TTS, and the degree of effect was a function of the duration of exposure.

2. Physiological Effects. Because the middle ear is the most susceptible part of the body to infrasound, it has been suggested that the physiological tolerance limit to infrasound will be determined by the middle ear. The pain threshold for the middle ear is 140 dB at 20 Hz. Perhaps for this reason many of the experiments which study the physiological effects of infrasound use noise levels around that threshold. Three papers examine the physiological effects of whole body exposure to infrasound including one (Mohr et al, 1965) previously discussed under auditory effects. Using 5 noise-experienced personnel, Mohr et al measured a number of physiological changes, both objectively and subjectively. They detected no significant objective effects, but point out that the objective tests were gross and would not necessarily be able to measure small changes which would not be noticed subjectively. Some subjects reported experiencing middle ear pressure build-up (which could be alleviated using valsalva), mild abdominal wall vibration, and at the extreme levels, chest wall vibration, voice modulation (although no change in speech intelligibility), mild middle ear pain, visual field vibration, and a feeling of gagging. None of these symptoms

were experienced when ear protectors were worn. The authors concluded that although the subjects felt that the exposures were "unpleasant", none of the levels experienced exceeded the voluntary tolerance limit.

The second paper (Slarve and Johnson, 1975) also examined the effect of infrasound on a number of physiological parameters. Four subjects were exposed to infrasound with a maximum level of 144 dB for 8 minutes. The authors found no effect on respiration rate, pulse rate and the general condition of the eardrum. They did find effects of middle ear pressure build-up (above 126 dB) and voice modulation and chest vibration (above 135 dB).

Again, one review paper (Johnson, 1975) provides details from a study not otherwise available to us. This is the study by Borredon (Centre de Recherches de Medecine Aeronautique, 1973), in which 42 subjects were exposed to infrasound (7.5 Hz) at 130 dB for 50 minutes. In this study a small increase in miminum arterial blood pressure was noted, although the effect was not statistically significant. In addition, some subjects reported feeling "drowsy", although there was no objective measurement to back this up as a definite effect.

In general, the papers examining the physiological effects of noise appear to be well done, with the conclusions well supported. All 3 studies seem to be in agreement that no serious physiological effects can be measured at levels which are most commonly experienced. The most important effects noticed were subjective ones, which were found in each experiment.

3. Performance Effects. Six papers examined the effect of infrasound on either balance or other tasks (Table 1). The first paper (Green and Dunn, 1968) examined the effect of naturally occurring infrasonic waves (from weather systems) on the incidence of automobile accidents and school absenteeism. It differs from the rest of the papers as it examines the effects of infrasound which is theorized through the examination of historical weather records rather than actually measured. Although the authors found some evidence of increased accidents and absenteeism during periods of supposed infrasonic activity, there are many possible biases, including the effects of local weather conditions themselves on the outcomes measured.

The next paper (Evans and Tempest, 1972) measured visual nystagmus (involuntary eye movement in a horizontal, vertical or rotary direction) as well as reaction time and visual acuity for 25 subjects who were performing a shape recognition task. Evans and Tempest claim that the experiment measures the effect of transporation sources, but in fact the levels they use (130-146 dB) are above those normally found in motor vehicles. The authors report a significant nystagmus effect. However, this is refuted by Harris et al (1976), who state that examination of sample charts reveals that much of the eye movement can be accounted for by normal eye blinks. Evans and Tempest found no effect on visual acuity, but report a 30% increase in reaction time at levels of 115-120 dB. Unfortunately, this assertion in the text is not supported by any table or figure, and no statistical test of the change is reported, so it is impossible to assess the validity of their conclusion.

One review paper (von Gierke and Parker, 1976) reports additional data from experiments which further refute Bryan and Tempest's claim of nystagmus. The authors report on a number of experiments which measured visual nystagmus in both humans (142-155 dB exposure) and animals (158-172 dB). In no case was visual nystagmus observed.

In another review paper, Johnson (1975) reports on a rail balancing task in which subjects were exposed to infrasound of various frequencies at levels up to 140 dB. There was no significant effect on rail task performance. In addition, Johnson reports personal experimentation with a balancing task at levels of 165 and 172 dB, and found no effect.

Two papers deal with the effect of infrasound on task performance. Harris and Johnson (1978) examined cognitive performance using serial search and complex counting tasks. They found no significant effect for exposure lengths of 15 and 30 minutes, for various levels of infrasound. They conclude that very high levels of infrasound are necessary to produce effects on performance. Kyriakides and Leventhall (1977) compared the effects of infrasound, audible sound and alcohol. They utilized a high priority pointer-following task in conjunction with both central and peripheral components of a secondary task. The subjects were exposed to a level of 115 dB for 36 minutes while performing the task. The authors found that this level had no significant effect on performance of either the primary or secondary tasks. However, they observed a difference in performance over time between the infrasound and audible sound conditions. In the presence of audible sound, performance was maintained over time, while a degradation of performance was evident when infrasound was present. This led the authors to conclude that there may be an effect on performance if the time of exposure were increased.

An effect of infrasound on task performance has not been established in the literature. The one paper which reports an effect (Evans and Tempest) has serious flaws in the measurement of the outcome parameters. The last two papers, which were well conducted and documented, show no significant effect of infrasound on performance. However, both of those papers suggest that an effect may be present at longer exposure durations.

Conclusions

From the literature reviewed here, we may make the following conclusions about the effects of infrasound:

1. whole body effects

   - middle ear pressure build-up at 130 dB
   - no subjective effects until > 150 dB.

2. auditory

   - some TTS for exposures > 137 dB
   - if exposure ≥ 30 minutes, TTS 14-17 dB
   - full recovery within 30 minutes.

3. respiratory

   - rhythm change at 130 dB.

4. performance

   - limit not reached
   - may be an effect if time of exposure > 40 minutes.

The authors of the review papers examined come to roughly the same conclusions, with a few additions. As far as auditory effects are concerned, they conclude that 150 dB is acceptable if exposure time is kept below 30 minutes (Johnson, 1980, p. 11). In addition, they report a definite effect on respiration at 166 dB from animal experiments (Johnson, 1980, p. 8). For performance effects, below 142 dB the only effect of infrasound is on speech interference (Johnson, 1980, p. 7). Finally, there is no vestibular effect up to 155 dB (Johnson, 1976, p. 8).

From the papers examined, we can conclude that infrasound must be regarded as at worst a small part of the problem of the health effects of noise. The literature has demonstrated that objective effects of infrasound are found only at quite high noise levels. The early reports of drastic effects were greatly exaggerated, a conclusion we share with most of the review papers examined. It is necessary to keep in mind, however, that these findings are applicable only to specific, short-term exposures. There has been no attempt to quantify the effects of low-level infrasound when exposure is of longer duration. Therefore, the question of possible effects of industrial exposure or exposure in motor vehicles remains unanswered.

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Table 1

Summary of Literature Assessed

Author	Problem Statement	Outcome	Sample	Noise Measure	Outcome Measurement	Analysis and Statistics	Possible bias and Confounders	Conclusions
Jerger, J. Alford, B. Coats, A. French, B. 1966	"...to explore the frequency region from 2 to 22 cps in an attempt to determine critical sound pressure levels leading to temporary threshold shift."	temporary threshold shift	19	119-144 dB 2-22 Hz 3 min.	noise level required to produce 10 dB threshold shift after 3 minutes of exposure	descriptive		-no clear-cut functional relationship between TTS and exposure signal -8 subjects no TTS, 11 subjects TTS 10-22 dB. -all TTS produced by exposure to 137-141 dB. -frequencies affected 3-8 K Hz
Mohr, G.C. Cole, J.N. Guild, E. von Gierke, H.E. 1965	to investigate human tolerance to high intensity, low frequency noise.	-auditory -physiology -voluntary tolerance	5	up to 150 dB 1-100 Hz 2 min.	-auditory acuity -voluntary tolerance subjective & objective: -visual acuity -spatial orientation -speech intelligibility -EKG -fine finger dexterity	not specified	-used only noise - experienced personnel -wore hearing protectors	-no significant objective changes -many severe subjective complaints -did not reach the voluntary tolerance limit.
Slarve, R.N. Johnson, D.L. 1975	"...to verify that the levels produced were safe for at least an 8 min. exposure."	physiological psychological	4	up to 144 dB 1-20 Hz 8 min.	-examination of tympanic membrane -audiogram -subjective: -vibration -respiration -psychological	not specified		-"no objective evidence (including audiograms) of any detrimental effect due to infrasound." -pressure build-up in middle ear, voice modulation, body vibration occurred consistently.
Green, J.E. Dunn, F. 1968	To see if distantly produced infrasonic waves (from weather systems) affected selected aspects of human behaviour	human behaviour	100 accidents claims 1500 students	75-95 dB theorized	incidence of -automobile accidents -school absenteeism	correlations	many possible e.g. effect of local weather conditions itself on parameters	-increases in times of intense disturbance "a correlation may exist"

Author	Problem Statement	Outcome	Sample	Noise Measure	Outcome Measurement	Analysis and Statistics	Possible bias and Confounders	Conclusions
Evans, M.J. Tempest, W. 1972	"...to see if infrasound, at the levels measured in vehicles has any effect on the sense of balance and psychological fitness of normal human observers."	balance and psychological awareness	25	130-146 dB 2-20 Hz 60 sec.	-involuntary eye movement - nystagmus -reaction time and visual acuity in a shape recognition task	none	random eye movements	-no effect on visual disturbance -some effect on reaction time (no gradient) -nystagmus evident; most pronounced at 7 Hz "...infrasonic noise has a significance in both comfort and safety in trasportation..."
Harris, C.S. Johnson, D.L. 1978	To assess the effects of infrasound on cognitive behaviour	task performance	I 12 II 12 III 16	-125, 132, 142 dB infrasound at 7 Hz -65 dB ambient -110 dB low frequency background I 15 min. II 30 min. III 15 min.	I. no of searches completed in serial search task II and III. % correct in complex counting task	analysis of variance		-no significant effects found "Very high levels of infrasound, more than 150 dB, may be necessary to produce decrements in cognitive performance."
Kyriakides, K. Leventhall, H.G. 1977	To assess the degree to which the performance of a number of tasks can be maintained or changed by exposure to infrasound	task performance	I 6 II 26	115 dB 2-15 Hz 36 min. control-70 dBA background	scores in central and peripheral tasks in following a moving pointer and responding to lights	analysis of variance -Wilcoxon		-no significant decrements in performance -degradation of performance over time -changes in performance over time different than for audible noise.