Noise and Health in the Urban Environment

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ABSTRACT

Noise, including noise from transport, industry, and neighbors, is a prominent feature of the urban environment. This paper reviews the effects of environmental noise on the non-auditory aspects of health in urban settings. Exposure to transport noise disturbs sleep in the laboratory, but generally not in field studies, where adaptation occurs. Noise interferes with complex task performance, modifies social behavior, and causes annoyance. Studies of occupational noise exposure suggest an association with hypertension, whereas community studies show only weak relations between noise and cardiovascular disease. Aircraft and road-traffic noise exposure are associated with psychological symptoms and with the use of psychotropic medication, but not with the onset of clinically defined psychiatric disorders. In carefully controlled studies, noise exposure does not seem to be related to low birth weight or to congenital birth defects. In both industrial studies and community studies, noise exposure is related to increased catecholamine secretion. In children, chronic aircraft noise exposure impairs reading comprehension and long-term memory and may be associated with increased blood pressure. Noise from neighbors causes annoyance and sleep and activity interference health effects have been little studied. Further research is needed for examining coping strategies and the possible health consequences of adaptation to noise.

KEYWORDS

noise, annoyance, mental health, heart disease

INTRODUCTION

One ubiquitous feature of urban environments is the exposure to environmental noise. Noise exposure is recognized by the public as an undesirable feature of the urban environment. In a French study linking the local environment and health as part of the Healthy Cities initiative, the two most important environmental problems were air pollution and noise /1/. Noise, defined as 'unwanted sound', is perceived as a pollutant and one type of environmental stressor. Exposure to excessive levels of noise in industry may induce hearing loss. There is also an expectation that such an environmental stressor as noise may have deleterious effects on other aspects of health, apart from hearing. Noise is undoubtedly perceived to be a nuisance, intruding into personal privacy, and causing annoyance and decline in the quality of

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life. If health is broadly defined to include quality of life and annoyance, then noise certainly affects health. In The Netherlands, environmental noise has been estimated to comprise 24% of the total environment-related health loss /2/. There is more controversy, however, as to whether noise causes illness. This controversy will be a large part of the subject of this review.

If noise does cause ill-health or even illness, what might be the mechanism for this effect? It is generally hypothesized that noise causes a disturbance of activities and communication, as well as annoyance, which will lead to stress responses and, hence, to symptoms and possibly overt illness /3/.

In the urban environment, such exposure may be from many different noise sources, including such transport as trains, aircraft, and road traffic; occupational noise exposure in factories; and building sites /4/. Because dwellings are built more densely in cities than in rural areas, domestic noise from neighbors is a major source of annoyance. Little systematic research has been carried out on the effects of domestic noise on health. This paper will include a review of the literature on the effects of noise from neighbors.

Characteristics of Sound and Human Responses

The response to noise may depend partly on various characteristics of sound, including the intensity, frequency, complexity of sound; the duration (whether intermittent or continuous); and the meaning of the noise. Studies of the health effects of noise differ in how much the different aspects of noise exposure are measured, perhaps because such studies often rely on long-term or retrospective evaluations of noise. Such disparity makes it difficult to compare different studies.

Scope of the Review

The non-auditory effects of noise, as dealt with in this paper, can be defined as 'all the effects on health and well-being that are caused by exposure to noise, with the exclusion of effects on the hearing organ and the effects that are due to the masking of auditory information (namely, communication problems)' /5/. Such effects include performance effects, physiological responses and health outcomes, annoyance, and sleep disturbance. This paper describes the research literature on noise exposure and sleep, social behavior, cardiovascular disease, the fetus, psychiatric disorder, annoyance; effects on such potentially vulnerable groups as children; and the combined effects of noise and other stressors on health. This paper also addresses the mechanisms that may explain the association between environmental noise and health, effect modifiers, and future research. This review paper has been developed and updated from an earlier review examining the need for new research in environmental noise /6/.

NONAUDITORY EFFECTS OF NOISE ON HEALTH

Noise and Sleep Disturbance

Both objective and subjective evidence for sleep disturbance by noise have been published /7–9/. Although noise effects on sleep may habituate over time /10/, small sleep deficits may persist for years /11/, with unknown effects on health.

Mechanisms of how noise exposure may affect sleep are manifold and not straightforward. Daytime exposure to noise preceding sleep may lead to a reduction in REM sleep /12/. Some have argued that this implies an increased demand for central nervous system recovery during sleep and, thus, deep sleep is augmented. Exposure to noise during sleep has shown that sleep disturbance is proportional to the amount of noise experienced, in terms of an increased rate of changes in sleep stages and in the number of awakenings. Whether this represents changes in the amount of sleep in each stage or is an effect of REM latency is not clear /13/.

Habituation occurs with an increased number of sound exposures by night and across nights. The probability of awakening seems to increase with the number of noise stimuli in the night but does seem to level off. Sleep awakenings can be measured in different ways: either behaviorally or by the electroencephalogram (EEG). Behavioral measures of sleep disturbance include the amount of body movements experienced during sleep. 'Large' body movements are associated with the number of awakenings. In the laboratory, no habituation occurred during 14 nights of exposure to noise at maximum noise level exposure /14/. Nevertheless, some habituation to the effect of number of noise events seemed to occur. Both noise events and background noise level have to be taken into account in assessing the potential for sleep disturbance, and the number of noise events exceeding a certain level is a useful measure. Objective sleep disturbance is likely to occur if there are more than 50 noise events per night, with a maximum level of 50 dB(A) indoors or more. Laboratory studies, however, lack ecological validity, and studies of real-life noise exposure and sleep are more likely to reveal whether long term noise exposure has any effect on sleep in the urban environment. In fact, a low association between outdoor noise levels and sleep disturbance has been found.

In the Civil Aviation Authority Study (1980) /15/ around Heathrow and Gatwick airports, the relative proportion of total sleep disturbance attributable to noise increased in noisy areas, but not the level of total sleep disturbance. In effect, the work suggested a symptom reporting or attribution effect rather than real noise effects. In a subsequent actigraphy study around four United Kingdom (UK) airports, sleep disturbance was studied in relation to a wide range of aircraft noise exposure over 15 consecutive nights /16/. Although a strong association was noted between sleep EEGs and actigram-measured awakenings and self-reported sleep disturbance, none of the aircraft noise events were associated with awakenings detected by actigram, and the chance of sleep disturbance with aircraft noise exposure of <82 dB was insignificant. Although it is likely that the population studied was one that was adapted to aircraft noise exposure, this study is also likely to be closer to real life than are laboratory studies with subjects who are newly exposed to noise.

Road-traffic noise at 50 to 60 dB(A) maximum increases the time taken to fall asleep. In particular, the number of noise events seems important in this effect /17/. The first third of the night is the time that is most vulnerable to sleep disturbance. Living less than 20 meters from a busy road has been found to predict insomnia in a study of Japanese women, adjusting for many relevant confounding factors /18/.

Does noise disturbance differ across demographic groups of the population? The best evidence suggests that older people are more affected by noise during sleep /19/. Sleep disturbance by noise was reported exclusively by an institutionalized elderly sample (55 to 96 years) compared with an age-matched non-institutionalized control group /20/. If anything, children seem less susceptible to noise disturbance during sleep, although they show a larger amplitude heart-rate response to noise during sleep /21/. Some studies suggest that women are more vulnerable than men are to sleep disturbance by noise, but the results are not consistent.

As far as physiological effects are concerned, noise exposure during sleep may increase blood pressure, heart rate, and finger-pulse amplitude, as well as body movements /21/. Not only may noise affect sleep but it may also have after effects during the day following disturbed sleep. In a community study of exposure to road traffic noise, perceived sleep quality, mood, and performance in terms of reaction time were all decreased following sleep disturbed by road-traffic noise /7/. The author argued that this impairment might have longer-term effects on psychosocial well-being. This hypothesis might be a possible mechanism through which noise might affect mood.

Noise exposure during sleep is considered to increase awakening or to cause shifts from deeper to lighter sleep stages. The effects shown in laboratory studies were more powerful than those in community studies, in which some adaptation may have occurred. Studies on noise abatement show that by reducing indoor noise level, the amount of REM sleep and slow-wave sleep can be increased /22/. It does seem that although some adaptation to sleep disturbance by noise may take place, complete habituation does not occur, particularly for heart rate during sleep. As little habituation is shown to heart rate responses to noise during sleep, protective mechanisms may be absent or less effective during sleep. If noise disturbs sleep, then after effects, such as lowered mood and diminished performance the next day, may occur. Such effects are presumably secondary to lack of adequate sleep.

What are the implications for long-term health effects resulting from sleep disturbance? Some studies have found that sleep disturbance may predict coronary heart disease (CHD). In a community study, persons reporting noise-induced sleep disturbance had an increased risk of reported angina pectoris (RR=1.86) and reported hypertension (RR=2.32) /23/. It is not clear from this study whether the sleep disturbance or the illness came first. This aspect can only be examined further in a longitudinal study.

Noise Exposure and Performance

There is good evidence, largely from laboratory studies, that noise exposure impairs performance /24/. Several studies have shown that performance may be impaired if speech is played while a subject reads and remembers verbal material, although this effect is not found with non-speech noise /25/. The effects of irrelevant speech are independent of the intensity and meaning of the speech. It has been suggested that the effect of speech is on memory rather than on perception /5/. The susceptibility of complex mental tasks to disruption by irrelevant speech suggests that reading, with its reliance on memory, may also be impaired. Jones /26/ has reviewed experiments on the effects of irrelevant speech on proof reading; in these studies it seems that the meaning of the speech was important, with meaningful speech being more disruptive than meaningless speech. This research seems relevant to office workers, especially those working in open-plan offices.

Some studies examined the subjects' perceived control over noise and found this aspect and the predictability of noise to be important in determining the effects and after-effects of noise exposure. Glass and Singer /27/, found that tasks that were performed during noise were unimpaired, but tasks that were performed after noise had been switched off were impaired. This impairment, however, was reduced when the subjects were given perceived control over the noise. Indeed, even the anticipation of a loud noise exposure in the absence of real exposure may impair performance, and the expectation of control counters this effect /28/. This finding may be relevant to urban environments in which the inhabitants may have limited control over a number of aspects of their lives.

Willner and Neiva /29/ examined the effects of exposure to brief, uncontrollable noise on the recall of information from memory. The authors found that uncontrollable loud noise increased the recall of negative trait words and suggest that noise induces a state of learned helplessness, which is similar to that found in depressed patients. Other studies /30/, however, have argued that perceived control may not be important in all experimental situations, and that the previous task situation is most important in determining whether after-effects occur. Exerting control over a threatening stimulus may reduce anxiety only when such control is easy to exercise. Indeed, the effort that is required to exercise control may result in a physiological arousal similar to that in those who have no assumption of control /31/.

The after-effects of noise exposure have also been studied following sleep: for instance, Wilkinson and Campbell /32/ report that reducing noise exposure during sleep by the insulation of double glazing led to improved simple reaction time the next day.

Smith and Stansfeld /33/ compared the self-reports of everyday errors (failures of attention, memory, and action), given by subjects living in an area of West London having a high level of aircraft noise, with those in a similar group living in an area of West London having a low level of aircraft noise. The high-aircraft-noise group reported a higher frequency of everyday errors, and so did the noise-sensitive subjects. No interaction occurred, however, between noise sensitivity and the level of aircraft noise. Longer-term memory and mental arithmetic were both impaired in noise-sensitive subjects in comparison with less-sensitive subjects under noisy conditions—55 dB(A), 75 dB(A)—but not in quiet conditions /34/. Some concern has been expressed that there may be some confounding by neuroticism in these findings and, in fact, studies of the effects of noise on cognitive tasks do suggest that neuroticism and anxiety are important in determining individual differences in the response to noise. For instance, Von Wright and Vauras /35/, showed that intermittent noise impaired retrieval for semantic memory in neurotic subjects, but had little effect on semantic memory of stable subjects.

Because arousal varies according to the time of day, the effects of noise have been suggested to vary with time of day, but in practice this has not been consistently found /36/. In occupational studies, the possibility of an interaction between noise exposure and working at night has been examined. Effects on performance were found for both noise and night work, but the effects were independent and varied according to the nature of the task being performed /5/.

Noise and Memory

Several studies have suggested that noise slows rehearsal in memory /37/. Overall, the results examining memory suggest that even moderate-intensity noise may have an effect on verbal memory tasks. Evidence has also been presented that noise may influence processes of selectivity in memory and attention. Hockey and Hamilton /38/ found that 80 dB noise impaired the recall of task-irrelevant information, but improved the recall of relevant information. The effects of selectivity, however, have not been consistently found in experiments on noise. As Smith and Broadbent /5/ comment:

> '*studies have shown that moderate intensity of noise does influence performance*' but '*they also reveal the inadequacy of most theories that suggest that performance is shifted by noise in an invariant or mechanical fashion. Changes in the difficulty of the task, subject to prior experience and changes in other task parameters may abolish or even reverse certain effects. Many of the tasks affected by this level of noise have used verbal materials and this made it initially attractive to think in*

terms for an effect of noise on internal speech. However, verbal tasks often present subjects with several ways of doing a task and noise may change the relative efficiency of performing in one way rather than another.'

Thus, the choice of strategy in performance in noisy conditions can act as a buffer against the effects of noise /39/. Noise may tend to reinforce the use of a dominant strategy for task performance. Noise may influence the allocation of resources to tasks according to priority, may alter the efficiency of control processes, and may make subjects more inflexible by impairing switching between cognitive strategies /5/. Interestingly, voluntary effort may be used to compensate for the potentially deleterious effects of noise on human performance. For instance, Tafalla and colleagues /40/ tested this theory in a study of the effects of noise on a complex mental arithmetic task. Reaction time increased on the task during exposure to noise, but only in low-effort conditions. Noise had no effects on performance under high-effort conditions, but systolic and diastolic blood pressure did increase during the high-effort conditions in noise.

Noise and Social Behavior

This area of noise research is very important because many human activities involve social interaction, which may relate not only to communication but also to health. This aspect is a particular issue in urban communities. Many effects of noise on social life reflect the direct effects of noise on communication. Evidence suggests that noise may reduce helping behavior, increase aggression, and reduce the processing of social cues that are seen as irrelevant to task performance.

Jones et al. /41/ have summarized the effects of noise on social performance.

- First, noise may act as a stressor, causing unwanted aversive changes in affective state;
- secondly, it may mask speech, interfere with communication, and might logically lead to social isolation; and
- thirdly, noise may give rise to attentional changes away from social cues.

Siegel and Steele /42/ found that noise affects the ability to weigh and to integrate information and leads to a choice of more extreme judgements. Evidently, in noise conditions, some involuntary choices are made, and the range of possible task strategies is reduced.

NOISE AND CARDIOVASCULAR DISEASE

Physiological Responses to Noise Exposure

Noise exposure causes a number of predictable, short-term physiological responses that are mediated through the autonomic nervous system. Such responses have generally been measured as changes in blood pressure, heart rate, depth and rate of respiration, pupil size, skin conductance, muscle tension, and endocrine outputs. Exposure to noise causes physiological activation, including increased heart rate, increased blood pressure, and peripheral vasoconstriction, and thus increased peripheral vascular resistance. The orienting reflex is the usual physiological response to noise /43/, unless the noise is loud enough to produce a defense/startle reflex /44/. The orienting reflex occurs in response to a stimulus that is either novel or indicates conflict or has learned significance. Defense/startle responses are evoked either by novel sounds or by sounds implying threat. Rapid habituation to brief noise exposure occurs, but habituation to prolonged noise is less certain, especially heart rate responses to noise exposure during sleep /22/.

Laboratory Studies

In laboratory animals, such as monkeys, chronic exposure to noise leads to the persistent elevation of blood pressure /45/. The striking evidence from animal studies has prompted researchers to examine the hypertensive effects of noise on humans in the laboratory. Such studies, however, have not been very consistent: in police officers exposed to traffic noise (60 dB Leq); the mean systolic and diastolic blood pressure rose in some individuals but fell in others /46/. It may be that in noisy conditions, some groups, especially those with a predisposition to hypertension, are more vulnerable to increased blood pressure than others.

Studies of noise and cardiovascular disease have tended to concentrate on CHD as the most prevalent form of coronary disease and have measured the most accessible indicators of cardiac function, such as blood pressure and heart rate. Increased blood pressure and heart rate may, on the one hand, be a result of stressor exposure and on the other hand, be indicators of increased predisposition to CHD.

The effect of sound on the auditory system is transmitted to the Reticular Activating System and thus to the hypothalamus, in which both further neuronal stimulation is activated, and the hypothalamic pituitary-adrenal axis may be stimulated. In addition, Ising /47/ suggests that noise may stimulate the secretion of adrenal medullary hormones, including noradrenaline and adrenaline. He postulates that familiar noise may induce the secretion of noradrenaline and unfamiliar noise, adrenaline. The effects of these two hormones will be to raise peripheral resistance and to increase blood pressure and heart rate. Whether these effects observed in laboratory conditions will have the same effect during long-term noise exposure, and how much adaptation occurs, is unclear.

In the etiology of CHD, Jansen /48/ suggests that environmental factors may influence (secondary) risk factors, such as social status, which in turn influence primary risk factors, such as blood pressure, blood lipids, and blood coagulation through a mediating stage of emotional disturbance, such as discontent, anxiety, and aggression. This model, quoted in Passchier-Vermeer /49/ is complex. Although both 'primary' and 'secondary' are risk factors for CHD, and good evidence exists for potential emotional mediators being risk factors for CHD, conclusive evidence that the primary risk factors are linked to the secondary risk factors through these mediating emotional disturbances has not yet been published.

Occupational Studies: Noise and High Blood Pressure

The strongest evidence for the effect of noise on the cardiovascular system comes from studies of blood pressure in occupational settings /50/ (see Table 1). Nevertheless, positive effects have been demonstrated in only a few of such studies, which partly relates to the study design. Many studies are cross-sectional, with difficulties in establishing both the direction of causation and the accurate estimation of noise-dose exposure. To have a persistent effect in raising blood pressure, noise may have to be of a certain intensity and be present for a certain length of time. Many occupational studies have suggested that individuals who are chronically exposed to continuous noise of 85 dB or greater had higher blood pressures than did those who had not been exposed to noise /51–53/. In many of these studies, noise exposure has also been an indicator of exposure to other factors, both physical and psychosocial, that are also associated with high blood pressure. Unless the other risk factors are controlled, spurious associations between noise and blood pressure may arise. Few studies have taken into account other potential confounding factors like smoking and antihypertensive

TABLE 1

Occupational Studies of Noise Exposure and Blood Pressure

Investigators	Type of Study	Sample	Sample Size	Noise Intensity	Health Measures	Hypertension risk factors controlled for	Findings
Herbold et al, 1989	Cross-sectional	Community sample of men 30 to 69 yrs	1046	Self reported road traffic noise	SBP ≥160mm Hg DBP ≥95mm Hg	Age, body mass index (BMI), alcohol consumption	Stratified results suggest noise relates to hypertension. Not confirmed in multivariate analysis
Green et al, 1991	Cross-sectional	Israeli male industrial workers	191	74–102 dBA		Age, involvement in physical work, smoking Quetelets Index, hearing loss using of hearing protectors	SBP, DBP raised in younger but not older workers
Zhao et al, 1991	Cross-sectional	Female Chinese textile mill employees	1101	75–104 dBA	SBP ≥160mm Hg DBP ≥95 mm Hg	Age years of work, salt intake, family history of hypertension	Dose - response relationships in SBP and DBP
Lang et al, 1992	Cross-sectional	Parisian workers	7679	≥85 dBA/8 hr d		Age, BMI, alcohol consumption, occupational category	SBP, DBP related to noise. Not confirmed in multivariate analysis
Fogari et al, 1994	Case control	Metallurgical factory workers	8811	≤80 dB (n=8078) vs 80 dB (n=733) y	DBP ≥95 mm Hg	Age, BMI, duration of employment	Heart rate, DBP not differ SBP higher in noise
Hessel & Sluis-Cremer, 1994	Cross-sectional	White South African miners	2197	–	SBP ≥140mm Hg DBP ≥90mm Hg	Age, BMI	No noise effects on blood pressure
Kristal-Boneh et al.	Cross-sectional	Blue collar workers from 21 Israeli industrial plants[1]	3105	80 dB(A)	Means only used	Age, smoking coffee & cholesterol, industrial sector, physical work load	Noise exposure correlates with resting heart rate (significant in men) and DBP only in women

[1] 60% response rate

medication. Occupational noise exposure may also have other effects on health. Occupational noise exposure has also recently been linked to greater risk of death from motor vehicle injury /54/ and is among the factors predicting disability retirement /55/.

Noise exposure, hearing loss and blood pressure. One method of assessing the impact of occupational noise on blood pressure has been to use hearing loss, attributed to occupational noise exposure, as a proxy measure of noise exposure. In addition, some have hypothesized that hearing loss may be a mediating step between noise and hypertension. In several studies /56–58/, higher levels of systolic and diastolic blood pressure have been associated with hearing loss, largely in older workers. In a study by Talbott et al. /58/, a careful adjustment was made for potential confounding factors, although a follow-up study among retired workers from the same plant failed to show a relation between hearing loss and blood pressure. This approach, however, has potential problems, especially that hearing loss may be associated with elevated blood pressure and CHD independently of noise. Possibly, hearing loss is related to changes in blood lipids or in coagulation, which is also independently related to blood pressure (or makes the ear more vulnerable to noise induced changes).

Noise, annoyance, and blood pressure. One possibility is that the effects of noise on blood pressure are mediated through an intermediate psychological response, such as noise annoyance. Lercher et al. /59/ found in a community based cross-sectional study that occupational noise annoyance was linked with a 2.1 (–3.0, 7.3) mm Hg increase in systolic blood pressure and 3.5 mm Hg (0.3, 7.4) increase in diastolic blood pressure, after adjustment for age, body mass index (BMI), sex, education, smoking, and other occupational risk factors. The combined effect, however, of noise annoyance and low work satisfaction was twice as large on blood pressure (systolic BP 7.5mm Hg [0, 15.0]; diastolic blood pressure 6.3 mm Hg [0.6, 12.4]). A similarly large effect was found for the combination of night shift work and noise annoyance.

The interpretation of the results of this interesting study is not straightforward. Whether noise annoyance is a good proxy measure of occupational noise exposure or whether it is also a proxy for other factors, such as socio-economic status (either via noise exposure or independently), is not clear because social status may have a powerful independent influence in blood pressure. The combination of work satisfaction and noise annoyance might amplify such a social-class effect. The literature on noise, annoyance, and mental ill-health suggests that although annoyance levels and mental ill-health are strongly associated and that noise and annoyance are strongly associated, annoyance is not the mediating factor between noise and ill-health; the same premise may apply to blood pressure. On the other hand, despite small numbers and a response rate of 68%, the results of this study were adjusted for education and possibly are not confounded. Further longitudinal studies, including the measurement of noise exposure, are needed. In young men who are exposed to industrial noise, noise annoyance and noise exposure have recently been found to have additive effects on serum cholesterol levels /60/. This finding might be another way in which noise annoyance might be linked to cardiovascular disease.

Noise and CHD in the Community

In a community survey of 6,000 people, aircraft noise exposure was found to be related to increased medical treatment for heart trouble and hypertension, increased cardiovascular drug use, and higher blood pressure /61/. The results could not be explained by age, sex, smoking, height/weight, or socio-economic differences.

One study that has extensively examined noise exposure and the risk of CHD is the Caerphilly Collaborative Heart Disease Study /62, 63/. The results from this study are not very consistent in terms of the effect of noise on the risk factors for CHD; statistically significant effects were reported for the effect of noise on systolic blood pressure (but not on diastolic pressure), total cholesterol, total triglyceride, blood viscosity, platelet count, and blood glucose level.

Is noise exposure a risk factor for myocardial infarction (MI)? In a case-control study of 693 men aged 31 to 70 years, noise exposure was related to increased risk of MI, with a population attributable risk of 33%, but the response rate in the study seemed low, the reporting of noise exposure was subjective, and no adjustment was made for possible confounding factors like work characteristics /64/. In summary, community studies have provided little evidence that environmental noise is related to hypertension, but some evidence suggests that environmental noise may be a risk factor for CHD (Relative risk 1.1–1.5) /65/.

Noise and Heart Rate

In a laboratory study, subjects who were exposed to 75dB(A) sound for 15 min exhibited higher heart rates after noise exposure, as compared with pre-stimulus levels /66/. Heart rate responses to noise were greater in men than in women, but no greater effects were found in anxious subjects. In these experiments, brief peripheral vasodilation, not vasoconstriction as might be expected, also occurred in response to noise /67/. Novel noise exposure in the laboratory, however, is a somewhat artificial testing situation.

In an occupational setting, in males only the resting heart rate correlated positively and significantly with noise exposure, particularly above 80 dB(A); the effect, however, was abolished by controlling for confounders. Although no difference was seen in the baseline heart rate, the mean resting heart rate of noise-exposed workers after approximately 4 h exposure to noise was higher than that in those not exposed to noise, suggesting an acute rather than a chronic effect of noise /68/.

A sudden intense exposure to noise may stimulate catecholamine secretion and precipitate cardiac dysrhythmia. Nevertheless, neither studies in coronary care units on the effect of speech noise nor studies on the effect of noise from low altitude military flights on 68 cardiac patients on continuous cardiac monitoring indicated that noise caused changes in heart rate or induced ventricular extra systoles /69/.

Effects of Noise Exposure in Pregnancy

In a case control study of 210 American mothers and 1260 controls, preterm birth (<37 weeks pregnancy) was significantly related to self-report of high occupational noise exposure /70/. Noise exposure, however, does not seem to have been included in the final model, the response rate was low, and the study was based wholly on retrospective reports. In a study of 200 Taiwanese women, noise exposure, measured by 24-h personal dosimetry (52.4–86.8dB(A) Leq) on three occasions during pregnancy, was not predictive of infant birth weight /71/. Furthermore, occupational noise exposure, road-traffic noise exposure, and listening to amplified music during pregnancy were not related to birth weight. The protocol for this study improved on those of earlier studies by adjusting for social class, smoking, and alcohol use, maternal weight gain in pregnancy, infant gender, and gestational age. Passchier-Vermeer /49/ summarizes the results of 10 studies examining the effect of noise on the unborn child and finds no conclusive evidence of low birth weight or congenital defects being related to noise exposure.

Future studies must develop better measures of noise exposure during pregnancy and must continue to control for factors that may confound the association between noise and low birth weight.

Endocrine Responses to Noise

The most convincing evidence relating exposure to noise and increased hormone secretion is in relation to noradrenaline and adrenaline. Buczynski and Kedziora /72/ found that in exercising men, impulse noise caused increases in noradrenaline, whereas pulse noise leads to an increase in the secretion of adrenaline. Cavatorta /73/ found that glass workers exposed to 96 dB(A) noise had 70% higher noradrenaline and adrenaline levels than did a control group working in a machine shop. The investigators also measured cortisol but found no increase in this study. It is not clear if the effects of other job characteristics, which might also have contributed to the elevated hormonal levels, were fully controlled for in this study.

In 50 female workers who were exposed to machinery noise [93–100 dB(A)], urinary catecholamine levels were higher than those in 25 female workers in quieter working environments [71–75dB(A)] /74/. Cortisol levels shared this trend. On the second day of testing, during which the noise-exposed workers wore earplugs, their catecholamine excretion decreased, and they reported less fatigue. These findings of increased catecholamines across studies have not all been consistent, however. Follenius et al. /75/ found no effect on noradrenaline, adrenaline, dopamine, growth hormone, or ACTH after exposure to intermittent noise between 45–99 dB(A). The authors did, however, find that noise exposure seemed to halt the circadian decline in cortisol, measured in the urine between 10:00 and 12:00 in the morning. Other studies also found a significant rise in cortisol in relation to noise /76/. Few studies have been done in children, but Hygge /77/ found increased adrenaline and noradrenaline in children who had been exposed to chronic aircraft noise around Munich airport.

Other hormones, apart from the catecholamines and those of the hypothalamic-pituitary-adrenal axis, have also been studied. Beardwood /78/ found that more than half a normal subject sample, exposed to monotone stimulation, had increased gonadotropin output and suggested that this increase might result from a failure of habituation because of attention paid to the noise signal. There is a suggestion here that the meaning of the noise may be important in determining response. The general pattern of endocrine responses to noise is commensurate with noise as a stressor, exciting short-term physiological responses to deal with stressors.

NOISE AND PSYCHIATRIC DISORDER

The association between noise and mental health has been examined using a variety of outcomes, including (at the simplest level), individual symptoms, as well as psychiatric hospital admission rates, the use of health services, and community surveys of common mental disorder.

Noise exposure may have psychological, behavioral, and somatic effects. Noise exposure has been postulated to create annoyance, which then leads on to more serious psychological effects. This pathway remains unconfirmed, rather what does seem to be true is that noise causes annoyance, and that independently, mental ill-health probably increases such annoyance. Nevertheless, as Van Dijk /79/ suggests, minor psychological disturbance, (for example, tension, irritability, difficulty in concentrating) rather than psychiatric disorder is likely to be a sequel of noise annoyance and to feedback to increase annoyance.

A more sophisticated model /80, 49/ incorporates the interaction between persons and their environments. In this model, persons readjust their behaviors in noisy conditions to reduce exposure. An important addition is the inclusion of the appraisal of noise (in terms of danger, loss of quality, meaning of the noise, challenges for environmental control, and so on) and coping (the ability to alter behavior to deal with stressor). This model emphasizes that dealing with noise is not a passive process. As in other mechanisms for noise effects, the possibility always exists that such effects are spurious, and that noise is merely a marker of other hazardous environmental conditions. This hypothesis does not rule out the possibility that noise acts through moderating other stressors or through its effects being moderated by other factors, such as perceived control or coping strategies.

Noise Exposure and Psychological Symptoms

The symptoms that are reported among industrial workers who are regularly exposed to high noise levels in such settings as weaving mills /81/, jet aircraft test beds /82/, schools /83/, and factories /84/ include nausea, headaches, changes in mood, argumentativeness, anxiety, and sexual impotence. More self-reported illness and illness-related absenteeism /85/, social conflicts at work and home /86/, and actual absenteeism /87/ have been found in noisy rather than in quiet industries. Many of these industrial studies are difficult to interpret, however, because in addition to excessive noise, workers were exposed to other stressors, such as physical danger and heavy work demands, which may be more potent than noise in causing symptoms. There may also be a differential selection of individuals working in noisy areas. For instance, jobs in noisy areas may be less desirable, may be more difficult to fill, and hence may attract individuals with health problems that have prevented them from attaining more desirable jobs. On the other hand, health factors may operate in the selection of personnel for jobs in high noise exposure areas that may be dangerous, demanding a toughness and resilience that is not required for those in quieter areas (for example, few symptoms were found among men working in high noise on aircraft carriers /88/. Also, the choice of coping strategies by individuals may influence whether aircraft noise actually causes symptoms; evasive coping strategies were related to higher scores on the Hopkins Symptom Check List in areas of high exposure to aircraft noise /89, 49/.

Community Studies of Noise and Symptoms

Environmental noise experienced outside work settings, although less intense, tends to be more difficult for the ordinary citizen to avoid. Community surveys have found that high percentages of people reported ‘headaches’, ‘restless nights’, and ‘being tense and edgy’ in high noise areas /41, 90–92/. An explicit link between aircraft noise and symptoms emerging in such studies raises the possibility of a bias toward the over-reporting of symptoms /93/. Notably, a study around three Swiss airports /94/, which did not mention that the study was related to aircraft noise, did not find any association between the level of exposure to aircraft noise and symptoms. In a West London Survey /95/, ‘tinnitus’, ‘burns, cuts and minor accidents’, ‘ear problems’, and ‘skin troubles’ were all more common in areas of high noise exposure. Acute symptoms ‘depression’, ‘irritability’, ‘difficulty getting off to sleep’, ‘night waking’, ‘skin troubles’, ‘swollen ankles’, and ‘burns, cuts and minor accidents’ were particularly common in high noise. Apart from ‘ear problems’ and ‘tinnitus’, however, 20 of 23 chronic symptoms were more common in low-noise environments. Symptoms did not increase with increasing levels of noise, which is possibly related both to a greater social disadvantage and its associated ill-health among residents in low aircraft-noise-exposure areas and to the possible unwillingness of chronically unhealthy individuals to move into potentially stressful high noise exposure areas. Nevertheless, such factors would not exclude an effect of noise in causing some acute psychological symptoms. Many of the effects of noise in industrial and teaching settings may, in fact, be related primarily to disturbances in communication.

Noise Exposure and Mental Hospital Admission Rates

Much of the concern with the possible effects of noise on mental health began with the study of admissions to psychiatric hospitals from noisy areas. Early studies found associations between the level of aircraft noise and psychiatric hospital admissions, both in London /96/ and in Los Angeles, California, USA /97, 98/. The results of these studies have been criticized on methodological grounds /99, 100/, and a replication study of Abey Wickrama's study by Gattoni and Tarnopolsky /101/ failed to confirm these findings. Jenkins et al. /102/ found that age-standardized admission rates to a London psychiatric hospital over 4 years increased as the level of noise of an area decreased, but lower-noise areas were also central urban districts, where high admission rates would be expected. In a further extensive three-hospitals' study /103/, high aircraft noise was associated with higher admission rates in two hospitals, but in all three hospitals, admission rates seemed to follow non-noise-related factors more closely; the effect of noise, if any, could only be moderating that of other causal variables, but not overriding them. Kryter /104/, in a re-analysis of the data, found "a more consistently positive relation between level of exposure to aircraft noise and admissions rates". One may conclude that the route to hospital admission is influenced by many psychosocial variables that are more potent than exposure to noise. Therefore, whether noise causes psychiatric disorder would be more suitably answered by studying a community sample.

Noise Exposure and Psychiatric Morbidity in the Community

In a community pilot study carried out in West London, Tarnopolsky et al. /105/ found no association between aircraft noise exposure and either General Health Questionnaire (GHQ) scores /106/, (dichotomized 4/5, Low scorers/High scorers) or estimated psychiatric cases /107/. This result was so even when exposure to road-traffic noise was controlled, except in three subgroups: (1) persons "aged 15 to 44 of high education" (41%, 14% $p<0.05$); (2) "women aged 15 to 44" (30%, 13% n.s.); and (3) those in "professional or managerial occupations". These authors expressed the guarded opinion that noise might have an effect in causing morbidity within certain vulnerable subgroups.

In the subsequent West London Survey of Psychiatric Morbidity /108/, 5885 adults were randomly selected from within four aircraft noise zones around Heathrow Airport, according to the Noise *and* Number Index. No overall relation was found between aircraft noise and the prevalence of psychiatric morbidity, either for GHQ scores or for estimated numbers of psychiatric cases, using various indices of noise exposure. An association was found, however, between noise and psychiatric morbidity in two subgroups: (1) 'finished full time education at age 19 years+'; and (2) 'professionals'. After these two categories (which had a strong association with each other) were combined, they showed a significant association between noise and psychiatric morbidity ($X^2 = 8.18$, df 3 $p<0.05$), but only for GHQ scores. Tarnopolsky and Morton Williams /108/ concluded that their results "show so far that noise *per se* in the community at large, does not seem to be a frequent, severe, pathogenic factor in causing mental *illness* but that it is associated with symptomatic response in selected subgroups of the population."

The possible relation between noise and psychiatric disorder was pursued further in a population that is unlikely to have been selected by noise exposure (which may be the case around a well-established airport, such as Heathrow). The association between road-traffic noise exposure, noise sensitivity, and psychiatric disorder, was examined in a study of the small town of Caerphilly, South Wales. In the longitudinal results, no association was found between the initial level of road-traffic noise and minor psychiatric disorder, even after adjustment for sociodemographic factors and baseline psychiatric disorder /109/. However, a small, nonlinear association was found between noise and increased anxiety scores /110/.

Psychosocial well-being has been shown to be reduced in areas exposed to high traffic noise, but the results have not been especially consistent and may be mediated through disruptive effects on sleep /14, 111/. A questionnaire study of 1053 residents around Kadena airport in Japan found no relation between noise and mental ill-health between 75–94 WECPNL, but did find a dose-response relation between noise exposure (75–95+ WECPNL and above) and depressiveness and nervousness /112/. In a British study of 7540 individuals, road-traffic noise, particularly the 'noise level in dB(A) exceeded for 10% of the time', was weakly associated with a five-item mental health symptoms scale /113/. This association remained after adjustment for age, sex, income, and length of residence. This scale included some clear mental health items, but also some that were less evidently related to mental health. Weaker associations with traffic count may relate to their skewed distribution, but it also seems that traffic noise level was more important than traffic flow. No interaction between noise exposure and noise sensitivity in determining symptoms was seen, as has also been reported in other studies /110/. Was the association due to noise exposure? Adjustment for the amount of 'noise heard' reduced the association very little, suggesting this was not the case, although 'noise heard' may not be well measured. More recent studies of very high noise levels suggest that there may be intensity thresholds of aircraft or road traffic noise above which psychological symptoms become more frequent /115/.

The use of health services has also been taken as a measure of the relation between noise and psychiatric disorder. Grandjean /94/ reported that the proportion of the Swiss population taking drugs was higher in areas with high levels of aircraft noise than in areas with low noise levels. In this study, an association was also found between the rate of contact with general practitioners and level of noise exposure. In the Heathrow study /116/, various health care indicators were used: (a) the use of drugs (particularly psychiatric or self-prescribed), (b) visits to the general practitioner, attendance at hospital, and (c) contact with various community services, but no indicator showed any clear trend in relation to levels of noise. This finding may relate to the differing distribution of ill-health by noise exposure, such that low-noise areas have more instances of chronic ill-health than do high noise areas.

Noise Annoyance, Noise, Symptoms, and Psychiatric Morbidity

Noise annoyance is associated, on the one hand with noise level and on the other with symptoms and psychiatric disorder. Against expectation, although a strong link was found between noise and annoyance, and those who were highly annoyed showed the greatest number of symptoms, symptoms were not more common in high noise than in low noise areas. This apparent paradox might be explained by the 'Vulnerability Hypothesis' /95/. According to this explanation, noise is not directly pathogenic, but rather sorts individuals into annoyance categories, according to their vulnerability to stress. Tarnopolsky et al. /105/ found that noise and minor psychiatric disorder were the strongest predictors of annoyance, and that having psychiatric morbidity led to annoyance, rather than vice-versa. Moreover, annoyance does not seem to act as an intervening variable between noise and morbidity. At any particular level of exposure, a wide individual variation occurs in the degree of annoyance that is expressed. Individual variance in annoyance can be explained largely in terms of noise sensitivity and attitudes to the source of the noise /117–119/.

Noise Sensitivity and Vulnerability to Psychiatric Disorder

Noise sensitivity, based on attitudes to noise in general /120, 121/, is an intervening variable explaining much of the variance between exposure and individual annoyance responses /122–126/. Individuals who are noise sensitive are also likely to be sensitive to other aspects of the environment /120, 123, 127–130/. This observation raises the question of whether noise-sensitive individuals are simply those who complain more about their environment. Certainly an association has been found between noise sensitivity and neuroticism /120, 125, 128, 131/, although such a relation has not been found in all studies /127/. On the other hand, Weinstein /132/ hypothesized that noise sensitivity is part of a critical-uncritical dimension, showing the same association as noise sensitivity does to measures of noise, privacy, air pollution, and neighborhood reactions. He suggested that the most critical subjects, among whom noise-sensitive individuals would be grouped, are not uniformly negative about their environment, but rather more discriminating than the uncritical group, who comment uniformly on their environment. It may be that noise sensitivity represents both aspects: being critically discriminating about the environment and having high neuroticism scores.

Noise sensitivity has also been related to current psychiatric disorder /108, 133–135, 129/. Stansfeld et al. /129/ found that high noise sensitivity was particularly associated with phobic disorders and neurotic depression, measured by the Present State Examination /136/. Similar to this association with phobic symptoms, noise sensitivity has also been linked to a coping style that is based on avoidance, which may have adverse health consequences /137/. Noise sensitivity may be partly secondary to psychiatric disorder; depressed patients followed up over 4 months became less noise-sensitive as they recovered. These 'subjective' psychological measurements were complemented by an 'objective' psychophysiological laboratory investigation of reactions to noise in a subsample of depressed patients. Noise-sensitive individuals tended to have higher levels of tonic physiological arousal, more phobic and defense/startle responses, and slower habituation to noise /121/. Thus, noise-sensitive individuals attend more to noises, discriminate more between noises, find noises more threatening and out of their control, and react to, and adapt to noises more slowly than do those who are less sensitive in this way. Through its association with a greater perception of environmental threat, its links with negative affectivity, and physiological arousal, noise sensitivity may be an indicator of vulnerability to minor psychiatric disorder /121/.

In the Caerphilly Study /109/, noise sensitivity predicted psychiatric disorder at follow-up after adjusting for baseline psychiatric disorder, but did not interact with the noise level, suggesting that noise sensitivity does not moderate the effect of noise on psychiatric disorder. After adjusting for trait anxiety at baseline, the effect of noise sensitivity was no longer statistically significant, suggesting that much of the association between noise sensitivity and psychiatric disorder may be accounted for by the confounding association with trait anxiety, so that constitutionally anxious people may be both more aware of threatening aspects of their environment and more prone to future psychiatric disorder. It seems possible that these might be linked.

NOISE ANNOYANCE

The most widespread and well documented subjective response to noise is annoyance, which may include fear and mild anger, related to a belief that one is being avoidably harmed /138/. Noise is also seen as intrusive into personal privacy, whereas its meaning for any individual is important in determining whether that person will be annoyed by it /139/.

Annoyance reactions are often associated with the degree of interference that any noise causes in everyday activities, which probably precedes and leads on to annoyance /140, 141/. In both traffic and aircraft noise studies, noise levels have been found to be associated with annoyance in a dose-response relation /108, 142–144/. There is continuing evidence of a dose-effect relation that is due to transportation noise /126/. Annoyance is also dependent on the context in which the noise is heard. Overall, it seems that conversation, watching television, or listening to the radio (all involving speech communication) are the activities that are most disturbed by aircraft noise /141/, whereas traffic noise, if present at night, is most disturbing for sleep.

Acoustic Predictors of Noise Annoyance in Community Surveys

One primary characteristic affecting the unwantedness of noise is the loudness or perceived intensity. Loudness comprises the intensity of sound, the tonal distribution of sound, and its duration. Judgements of noisiness and loudness of a series of aircraft and community sounds have shown small but significant differences /145/. The evidence is mixed on the importance of the duration and the frequency components of sound in determining annoyance. High-frequency noise has been found to be more annoying than low-frequency noise /146/. McKennell /147/ found that the short duration of Concorde flights over London appeared to offset, somewhat, the increased perceived loudness of the Concorde as compared with conventional jet aircraft. Correlations between noise and annoyance are lower for impulse than for continuous noise /119/. This correlation may be partly because of the smaller range of noise exposure in some studies but is also likely to result from the higher correlation between attitude and annoyance in impulse noise studies /119/. In most community surveys of noise, vibrations are perceived as a complement to loud noise and are found to be important factors in determining annoyance, particularly because they are commonly experienced through senses other than hearing /147/.

Complex interactions between background noise exposure and the number of noise events in determining annoyance have been found /148/. In terms of aircraft noise exposure, some evidence suggests that after a certain number of flights a ceiling effect on annoyance does occur, although the very small numbers of subjects who have been exposed to very high noise levels make this finding difficult to assess accurately. No evidence has emerged that ambient noise has a significant effect on noise annoyance that is related to target noises, such as aircraft, road traffic, railway, or impulse noise /149/. Generally, gender differences in annoyance have not been found. Age differences may relate to other factors, such as having young children or cohort effects /150/. The relation between social class and noise annoyance is inconsistent. If anything, higher socio-economic status is related to higher annoyance /151/, which may relate to expectations of higher standards of environmental conditions in those of higher socio-economic status. It may be that such individuals are more likely to complain about noise as well.

Taylor /140/, in a path model analysis of aircraft and traffic noise annoyance, found that noise sensitivity had a stronger effect than the aircraft noise level on annoyance and was the most important non-noise predictor of annoyance. Other predictors of annoyance include fear of the noise or noise source /152, 153/ and attitudes to the noise source. Such attitudes include the predictability and controllability of the noise, general dislike of the environment /118/, and attitudes to the noise source, including misfeasance /154, 155/. Less than 50% of annoyance surveys reviewed by Fields /156/ found that socio-economic factors influenced annoyance responses, but over 50% of the surveys found that after controlling for noise level, noise annoyance increases with

a) the fear of danger from the noise source,
b) sensitivity to noise,
c) the belief that the authorities can control the noise,
d) awareness of the non-noise impacts of the source, and
e) the belief that the noise source is not important.

Some limited evidence also points to personality traits, such as extraversion, predicting annoyance, but other studies have not found this /157/. In three information processing tasks, highly rigid subjects (on a scale of inflexibility) were more annoyed by noise and were more inaccurate on the tasks in noise than were more flexible subjects /158/.

NOISE AND NON-AUDITORY HEALTH EFFECTS IN CHILDREN

Individuals within populations that are exposed to noise may not be uniformly susceptible to the effects of noise on health /121, 159/, thus when assessing noise effects on health, focusing on exposure to noise in high-risk groups may be most productive. Older people may be more susceptible than younger persons to sleep disturbance in noise and possibly more vulnerable to the hypertensive effects of noise. The best evidence, however, of increased vulnerability to noise comes from studies of children. Children may be more susceptible than adults to environmental stress for a variety of reasons, including having less cognitive capacity to understand environmental issues and to anticipate stressors, and a lack of well-developed coping repertoires /160, 161/. Impairment of early childhood development and education by such environmental pollutants as noise may have life-long effects on achieving academic potential and health /161/.

Cognition

The most consistent effects of noise found in children are cognitive impairments, although such effects are not uniform across all cognitive tasks /160–162/. Tasks involving central processing and language comprehension, such as reading, attention, problem solving, and memory appear to be the most affected by exposure to noise /160–164/. This effect of environmental stress on cognitive tasks with high processing demands is widely accepted in the environmental stress literature examining the general sources of environmental stress on cognition /36, 160/.

Across both cross-sectional and longitudinal studies in pre-school children, Wachs and Gruen /165/ accumulated data indicating a negative association between home noise levels and cognitive development in children from 6 months to 5 years of age. The measures of cognitive development that were affected by noise include mental representations of objects, the use of objects as tools to achieve goals, and relating words to objects (see Evans and Lepore's /162/ review of cognitive results in this age group). The present review will concentrate primarily on the effects of chronic noise exposure on the health and performance of primary school children (aged 5 to 12 years) because (a) this is a critical learning acquisition period for children in which future learning patterns are established; and (b) the effects of chronic noise exposure at home and school have been examined in more recent, well-designed studies that have direct relevance to the health of children in the community. The studies reviewed in detail here focus exclusively on environmental noise effects (see Evans and Lepore's review for further discussion of laboratory studies and acute noise effects).

In studies examining the effects of chronic aircraft, rail, and road-traffic noise on school children's cognitive performance, the following results have been found in children who are exposed to high levels of environmental noise:

a) deficits in sustained attention and visual attention /166–174/.
b) difficulties in concentrating in comparison with children from quieter schools according to teachers' reports /83, 175–177/.
c) poorer auditory discrimination and speech perception /160, 163, 172, 178–180/.
d) poorer memory that requires high processing demands /162, 164, 181, 182/.
e) poorer reading ability and school performance on national standardized tests /163, 178, 180, 183–190/.

Some of the earlier research examining noise effects in children has serious methodological flaws, limiting the conclusions that can be drawn from the data. These flaws include the following:

a) data were not provided to indicate how well socio-economically matched the noise exposed children were to the control sample /169–171/;
b) the sample size was not large enough (most studies);
c) not enough schools to rule out a school effect confounding the results /160, 174, 179, 187, 191/;
d) statistical methods were not sensitive enough /174/; and
e) most studies were cross-sectional.

The results from field studies that controlled for socio-economic factors show that chronic noise exposure is consistently and reliably associated with cognitive impairments in school children /163, 166, 178, 179, 187, 192/.

In the 1970s, the first well-designed naturalistic field study was conducted by Cohen et al. /178/, who studied elementary school children living in four, 32-floor apartment buildings located on an expressway. The sample of 73 children was tested for auditory discrimination and reading level. Children living on the lower floors of the 32-story buildings (namely, higher noise levels) showed greater impairment of auditory discrimination and reading achievement than did the children living in higher-floor apartments. Bronzaft and McCarthy /184/ compared the reading scores of elementary school children who were taught in classes on a noisy side of a school near a railway line with the scores of the school children in classes on the quiet side of the same school. The investigators found that in children on the noisy side of the school building, performances on the school achievement tests were poorer than those in classes on the quiet side of the school. The mean reading age of children in the classes on the noisy side of the school was 3 to 4 months behind that of the children in the quiet classes. A strength of Bronzaft and McCarthy's /184/ results is that they cannot be attributed to self-selection, a methodological problem found in many field studies, because the noise effects were found in the same school. Children were not assigned in any systematic manner to classrooms on the noisy or quiet side of the school.

In a systematic, well-controlled, naturalistic field study around Los Angeles Airport in the 1980s, impaired performance on a difficult cognitive task was found in primary school children aged 8 to 9 years (cross sectional results /179/; longitudinal results /191/). Cohen and colleagues /179/ concluded that their results were strikingly similar to those reported in the laboratory setting, but that replication was required before definitive conclusions could be reached. In the 1990s, these effects were confirmed around Heathrow Airport in a repeated measures field study comparing the cognitive performance and stress responses of children aged 9 to 10 years attending 4 schools that were exposed to high levels of aircraft noise (>66 dB(A) 16 h Leq) with children attending 4 matched control schools that were exposed to lower levels of aircraft noise (<57 dB(A) 16 h Leq). Children tested at baseline were re-tested a year later at follow-up. The results indicated that chronic exposure to aircraft noise was associated with impaired reading comprehension and sustained attention after adjustment for age, main language spoken at home, and household deprivation /166/. The within-subjects analyses adjusting follow-up performance for baseline performance indicate that children's development in reading comprehension may be adversely affected by chronic aircraft noise exposure /166/.

The results of a multi-level modeling study, analyzing pre-existing national standardized scores of school performance in relation to aircraft noise around Heathrow airport for 11,000 scores of children aged 11, suggest that aircraft noise is associated with school performance in reading and mathematics in a dose-response function, but that this association is influenced by socio-economic factors /186/. The results of that study replicate those of an earlier study examining standardized school performance scores that was conducted around New York City airports /185/.

Stronger evidence to suggest the existence of noise effects comes from intervention studies and natural experiments, in which changes in noise exposure are shown to be accompanied by changes in cognition. To date, three studies have examined the effects of noise reduction on children's cognition: two intervention studies /183, 191/ with methodological flaws limiting their generalizability and one well-designed natural experiment called The Munich Airport Study /163, 182, 192/. The most convincing evidence for noise-related cognitive effects came from the prospective longitudinal natural experimental field research around Munich Airport in older children, with a mean age of 10.8 years (cross-sectional results /163/; longitudinal results /182/). In 1992, the old Munich airport closed and a new airport was opened. The cross-sectional results indicate an association between high noise exposure and poor long-term memory and reading comprehension /163/. Longitudinal analyses, after three waves of testing, indicate improvements in long term memory after closure of the old airport. Strikingly, after the new airport opened, these effects were paralleled by the impairment of the same cognitive skills /182/. Further research is required to clarify these findings in a larger sample of school children to examine causal mechanisms and to propose and test interventions.

Motivation

Chronic exposure to aircraft noise has been associated with decreased motivation in school children /160, 163, 179, 191/, although the results are not consistent /187/. In the Los Angeles Airport Study /179/, motivation was measured as persistence on a difficult cognitive task that had been preceded by a success or failure experience. The authors found that children in the high noise-exposed schools had poorer performances on soluble and difficult test puzzles and were more likely to give up on a difficult puzzle than were the children in quiet schools /179/. A year later at follow-up, the investigators replicated the puzzle-performance results, but did not find a noise effect on the rate of giving up /191/. With a new sample of school children around Los Angeles airport, Cohen and colleagues found that children in noisy schools failed a difficult puzzle more frequently and showed greater abdication of choice of rewards than did children from the quiet schools /160/. In Munich, children who were chronically exposed to high noise persisted less with an insoluble puzzle /27/ than did the control group of low-noise-exposed children /163/. This motivation effect may either be independent or be secondary to noise-related cognitive impairments.

Cardiovascular Effects

Certain evidence indicates that children are not only susceptible to cognitive impairment in noisy environments but also may react physiologically to noise in terms of raised blood pressure. Seven out of nine studies (from 1968 to 1990), reviewed by Evans and Lepore /162/, report elevations of resting blood pressure among children who are chronically exposed to aircraft and road-traffic noise. Even though methodological problems (such as noise levels not being high enough in high noise areas, unreliable noise measurements, selective attrition, lack of control of sociodemographic factors) seriously limit the conclusions that can be drawn from some of these earlier studies (for example, /170, 193/), the Los Angeles and Munich studies and two further studies in the 1990s /194, 195/ provide more reliable cardiovascular evidence.

In Los Angeles, cross-sectional results indicate small but significant increases in systolic and diastolic blood pressure, which are associated with chronic aircraft-noise exposure at school /160, 179/. The elevated blood pressure found in 1980 does not appear to habituate with continued exposure /160/. The ranges of blood-pressure elevation in noise-exposed children in these studies are within normal levels and do not suggest hypertension. In Munich, a relation was found between noise exposure and baseline systolic blood pressure and lower reactivity of systolic blood pressure to a cognitive task that is presented under acute noise /163/. The longitudinal results demonstrate that after the opening of the new airport, systolic blood pressure significantly increased in the noise-impacted communities /192/. Diastolic blood pressure and reactivity were unrelated to noise exposure in the Munich school children. In children aged 3 to 7 years, high levels of urban road-traffic noise (>60 dB(A) Leq) at school were associated with higher systolic and diastolic blood pressure and mean heart rate in comparison with children attending control schools having low levels of road-traffic noise /195/. This cross-sectional study provides very strong evidence that noise may lead to elevated blood pressure in children because (a) the sample size is large (1542 children), (b) 30 schools were examined, and (c) controls for age, body weight, height, and demographic and socio-economic factors were used in the analysis.

A study of 862 children aged 7 to 12 years compared the blood pressure of deaf-mute children (noise-insensitive group) and children with normal hearing (noise-sensitive group) who were exposed to high levels of road-traffic noise at 2 schools—

60–75 dB(A). A multivariate analysis showed the systolic and diastolic blood pressure of deaf subjects to be significantly lower than that of subjects with normal hearing, after adjustments for the effects of confounding factors /194/. This study is limited because assuming that 'noise exposure' is the only factor that affects blood pressure in deaf children is questionable, which makes deaf children a problematic control group. In a sample of 1230 children in the Sydney Airport Study /196/, no association was found between aircraft noise and blood pressure after adjustment for dietary, socio-economic, and anthropomorphic factors. This study, however, had a poor response rate of 40% of children within the schools, which suggests that the negative result could be due to a biased self-selected sample. Also, the noise-exposure levels were difficult to monitor.

Endocrine Disturbance

The Munich study was the first field study to examine the neuroendocrine indices of chronic stress among persons who are exposed to community noise /163/. The overnight resting levels of urinary catecholamines (adrenaline and noradrenaline) were significantly higher in children who are chronically exposed to aircraft noise than in unexposed children cross-sectionally around the old-airport /163/. Consistent with the elevations in blood pressure reported in the longitudinal analyses, adrenaline and noradrenaline increased sharply among children living in the flight paths of the new airport after it opened /192/. Evans and colleagues did not find an association between chronic aircraft noise exposure and cortisol level in either the cross-sectional /163/ or longitudinal /192/ analyses, nor was such an association found in the Heathrow Study /187/.

Noise Annoyance

Children have been found to be annoyed by chronic environmental noise exposure /163, 166, 184/. In Munich, children living in noisy areas were significantly more annoyed by noise in their community, as indexed by a calibrated community measure that adjusts for individual differences in rating criteria for annoyance judgements /163/. In London, noise annoyance was measured with child-adapted, standard self-report questions /156, 197/. The repeated measures analyses from the Heathrow study indicate that children's annoyance remains constant over a period of a year, with no strong evidence of habituation /166/. It is important to recognize that even young children report disturbance by environmental noise. In many ways, child noise annoyance may be less subject to bias than adult noise annoyance because children are less affected by other factors that influence annoyance in adult samples, namely, political and environmental attitudes.

Mental Health and Stress Responses

Only a few studies have examined child psychological disorders in relation to noise. Nurmi and von Wright /198/, when studying the interactive effects of noise and neuroticism and learning in school children, found that noise during learning impaired the subsequent recall performance of 'neurotic' subjects and of subjects with a high score of state-anxiety. Poustka and colleagues /199/ studied the psychiatric and psychosomatic health of 1636 children aged 4 to 16 years in two geographical regions that differed according to the noise made by jet fighters exercising frequently at low attitude. Psychological and neurological outcomes were not related to noise exposure. The authors found that certain relations with noise could be demonstrated in depression and anxiety beneath the threshold of clinical significance. The results are not convincing because (a) the areas differed socio-economically and the results were not adjusted accordingly; and (b) there was no adequate measure of the noise exposure. Chronic aircraft noise exposure was not associated with anxiety and depression (measured with psychometrically valid scales) after adjustment for socio-economic factors in the Heathrow study /187/. In Munich, however, children living in the noisy environment had lower psychological well-being than did children living in quieter environments /163/. The longitudinal data from around Munich show that, after the inauguration of the new airport, the newly noise-exposed communities show a significant decline in self-reported quality of life after being exposed to the increased aircraft noise exposure for 18 months (third wave of testing), as compared with a control sample /192/. These studies suggest that noise does not influence child mental health, although it may affect child stress responses and sense of well-being.

Vulnerable Child Groups and Individual Differences

Although overall trends show that chronic exposure to noise is associated with impaired cognition over a range of functions, there may be individual differences in these effects. Some children in the population may be more vulnerable to noise effects than others. Limited evidence shows that children who have lower aptitude /160, 190, 200/ or other difficulties, such as learning difficulties /201, 202/ and cerebral palsy /203/ may be more vulnerable to the harmful effects of noise on cognitive performance. The evidence is not conclusive because some studies have not found any noise effects with learning disabled and hyperactive children /181, 204, 205/. The findings, however, will depend on the sensitivity of the tests for the various populations.

Evans and Lepore /162/ claim that noise effects seem to be more pronounced in children from the upper elementary grades as compared with their younger counterparts /161, 178, 185, 188, 190/. Cohen and colleagues /160/ found that the longer the children had been attending the noisy schools, the stronger the effects. This age-related trend may be due to several reasons. Children in the upper grades generally have had longer noise exposure. It is also possible that cognitive measures may be more sensitive for older than for younger children and thus more reliable in measuring the harmful effects of noise. Although Evans and Maxwell /180/ found a significant noise effect on reading in children in younger grades (grades 1 and 2), it may be that the earlier studies did not detect noise effects in younger children because at this age, it is harder to measure reading and school performance reliably. The age at which noise exposure begins to affect children's cognitive functioning is still an open question.

Given that existing gender differences are known in various health and performance outcomes, it is possible that noise affects boys and girls differentially. Smith and Jones /206/ claim that evidence for gender differences in adults is inconclusive. In children, the pattern of results is equally inconclusive and contradictory. Ising and colleagues /207/ found that high levels of low-altitude military aircraft flights leads to an increase in systolic and diastolic blood pressure in girls but not boys; but conversely, the authors found that noise significantly increases heart rate in boys but not girls. Hambrick-Dixon /168/ found that high levels of acute train noise significantly affects the attention of girls aged 5 to 7 years, but has no effect on boys' attention. Christie and Glickman /208/ have also found that girls may be more distracted than boys by acute noise exposure. In studies of young children and infants, it would seem that in comparison with girls, boys are more susceptible to chronic noise-related problems /209–211/.

Possible Mechanisms of Noise Effects

The research evidence outlined above focused on how noise directly affects outcome variables as separate correlates, leaving us with the critical question of how does one explain the link between chronic exposure to noise and the adverse effects on child cognition and health? The theoretical understanding of child noise effects is very limited and is largely based on acute experimental research with adults. Only three studies /166, 178, 180/ have actually tested the mediating role of a hypothesized factor. The identification of mechanisms has relevance not only for the theoretical understanding of noise effects but also for intervention strategies to reduce the adverse noise effects (for example, educational interventions).

Children may adapt to noise interference during activities by filtering out the unwanted noise stimuli. This tuning-out strategy may overgeneralize to all situations when noise is not present, such that children tune out stimuli indiscriminately. This 'tuning-out' response is supported by the findings that children who are exposed to noise have deficits in attention, auditory discrimination, and speech perception /163, 172, 178/. Under certain circumstances, such strategies may be detrimental, and a hypothesis has been proposed that impairments in **attention, auditory discrimination,** and **speech perception** may mediate the association between noise and children's cognitive performance. Preliminary evidence indicates that the association between noise and reading performance is mediated by psycholinguistic mechanisms, specifically: auditory discrimination /178/ and speech perception /180/. Other evidence has shown that noise-related reading effects are not mediated by sustained attention /166/ and sound perception /180/.

Teacher frustration and communication difficulties could also be mechanisms for cognitive and motivation effects /161/. Chronic noise exposure may also affect communication in the class-room, which makes it more difficult for children to learn and for teachers to teach and may lead to frustration, interruption in speech, and reduced instruction time /83, 184/.

Learned helplessness has been proposed as a mechanism to account for the motivation effects /162, 163, 179/. The mechanism to account for the effects of noise exposure on children's blood pressure, endocrine disturbance, and annoyance is considered to be the same stress mechanism that has been proposed to account for the adult noise effects. Most child noise research has been exploratory and cross-sectional, which means that future research should examine the explanatory power of these cognitive and motivation mechanisms. In addition, the inter-relation between psychophysiological responses and cognitive noise effects must be examined.

COMBINED EFFECTS OF NOISE EXPOSURE AND OTHER STRESSORS

There is much debate over whether noise effects on health may be augmented by, or may augment in turn, the impact of other stressors on health. Stressors may act either synergistically, antagonistically, or not at all. Stressors may include physical, chemical, and biological factors, as well as the structure of the work task itself, the formal conditions of employment, and work relations /212/. Much emphasis has been placed on laboratory studies, without considering that the results of such studies may lack external validity.

Past research on combined effects has not considered common conditions and levels of stressors across studies, direct and indirect effects, long durations of exposure, and complex tasks

/213/. In a laboratory-based performance experiment involving 134 18- to 34-year olds, an interaction was found between having a cold and noise exposure on simple reaction time /214/. Little difference was found between healthy and cold subjects' performance that was tested in quiet, but for subjects tested in noisy conditions [70 dB(A)], performance was much slower for the cold subjects. This result was fairly specific because other tests showed the main effects of noise (for example, detection of repeated numbers task) or the effects of cold, but no interaction.

In a factorial design experiment in 60 healthy male subjects, noise and vibration had a statistically significant effect on diastolic blood pressure, and temperature and noise had a combined effect on the morning adrenaline secretion rate /215/, but these were only a few among many effects tested. Several studies have considered the combined effects of noise and vibration in drivers. A higher degree of physiological activation was found, indexed by raised heart rate, in those having to cope with noise and vibration simultaneously /216/. Some studies do not separate out the combined effects, for instance, noise and vibration exposure in furniture industry workers caused joint pain, chest pain, stomach disorder, headaches, tremor, and visual problems /217/.

Studies on night shift work and noise show conflicting results: Smith /218/ found that noise and night work had independent effects on performance testing, with generally no interaction with personality, except a small interaction with introversion. On the other hand, Koller et al. /219/ found that night-shift workers were more sensitive than day workers to noise, and this sensitivity was related to more health problems. Noise-sensitive shift workers could be more disturbed by noise while sleeping during the day, or a synergism might exist between the stressor of night work and occupational noise exposure that is moderated by noise sensitivity.

Noise may either act independently of other stressors or in a synergistic or antagonistic manner. Statistical interactions between noise and other stressors may be difficult to interpret and may depend on the method of analysis. Clearly defined conceptual models in this work are lacking, and the conflicting results are difficult to interpret. In addition, laboratory results may not generalize to field conditions, in which the pattern of stressors and their interpretation may be different.

Field studies suggest that the combined effects of multiple stressors are greater than the sum of their individual stressors /220/. It might be the case that noise will show more effects on health in individuals who are already exposed to other stressors. Few studies attempting to examine the effects of multiple environmental stressors have been done /160/. Multiple stressors might include

a) other physical stressors (for example, air pollution, poor housing conditions),
b) psychosocial stressors (for example, crowding, social isolation, fear of crime, perception of lack of control over the environment), and
c) adverse material conditions (low income, unemployment).

This is an important new area for the development of noise research.

DOMESTIC NOISE

Frequency of Complaints

Domestic noise, that is to say 'noise made by residents that is a nuisance to other neighbors' /221/, is now the greatest source of noise nuisance and public complaint. For example, the UK Chartered Institute of Environmental Health (CIEH) statistics reveal that the number of complaints made to Local Authorities (LA) about domestic noise have increased sharply in recent decades /222, 223/. In 1986, 46,803 complaints were made. By 1996/97, this figure had trebled, when the number of complaints peaked at 173,436. Although the seemingly inexorable rise in complaints about noise from neighbors appears to have abated, with the number of domestic noise complaints falling by nearly 15% to 148,006 in 1997/98, this figure represents 70% of the total number of noise complaints received by LAs in that year.

According to the national noise attitude survey conducted by the Building Research Establishment (BRE) in 1991 /224/, environmental noise spoils the home life of one in three persons to some extent and totally spoils the home life of one in one hundred. Noise from neighbors also provokes a greater proportion of objections, relative to the number of people who hear it, than do either road traffic or aircraft noise. Yet, only 3.6% of those who objected to domestic noise from all sources complained to their LA /225/, suggesting that the CIEH complaint statistics above are not a reliable index of noise annoyance and may represent only a tiny fraction of the total number of people who are affected by domestic noise. Another national survey, conducted by General Accident (in /225/), revealed that the biggest source of conflict between neighbors is noise of various kinds, with 20% of respondents mentioning loud stereo or radio music, and 13% mentioning noisy house maintenance work and noisy children. Similar figures are reported in Scotland, where, in a baseline study of housing management, one in five tenants had experienced problems with anti-social behavior during the previous year. Forty-three per cent of these complaints related to domestic noise /226, 227/. This finding was replicated in a study by the University of Stirling, in which representatives of residents from a number of housing estates listed domestic noise as the most commonly experienced problem /228/.

The effects of domestic noise on those who are subjected to it are numerous and in extreme cases, have the potential to be devastating. For example, during the 6-y period to December 1994, 17 fatalities that were purportedly associated with neighborhood noise complaints were documented /225/. Other sources suggest that there may be as many as 10 to 20 cases per year in which suicide can be attributed to noise from neighbors /229/. Such cases are obviously the exception, but even at a more mundane level, domestic noise can severely disrupt the lives of those affected, reducing the quality of life and having an adverse impact on mental and physical well being, causing annoyance, and disturbing sleep and daily activities. The World Health Organization defines health as 'not merely the absence of disease but a state of complete physical, psychological and social well-being'. In light of this definition, domestic noise, given its prevalence in the urban environment, is quite clearly a threat to the health of the nation. Whether domestic noise causes more serious health effects is unknown.

Despite the prevalence of domestic noise complaints, however, and the adverse impact on those involved, research in the field is limited and a there is a dearth of evidence on the effects of domestic noise. The evidence that does exist is derived largely from the CIEH Annual Reports; The Department of the Environment, Transport, and the Regions (DETR) Annual Digest of Environmental Statistics; the BRE National Noise Attitude Surveys; and the Noise Surveys that are conducted by the National Society for Clean Air.

A review of the findings of relevant research on domestic noise is given below. Because it is unlikely that domestic noise will be sufficiently intense or prolonged to cause physical damage to the auditory system, this review will focus on the following areas:

- non-auditory health and behavioral effects of domestic noise;
- socio-demographic and environmental factors that increase susceptibility to the effects of domestic noise;
- personal characteristics that may moderate the effects of domestic noise; and

- characteristics of the noise itself that may have an impact on its effects.

Health and Behavioral Effects of Domestic Noise

Little clear evidence is available about whether and to what extent exposure to noise is ultimately harmful to human health and well being, except at very high sound levels, when it causes hearing loss and tinnitus. Although laboratory studies indicate that levels of biochemical stress hormones, such as cortisol and the catecholamines, may increase in response to noise, no firm evidence has emerged on the effects of excessive neighborhood noise on psychophysiological indicators and measures of health /229/. Research has instead tended to focus on general or mental health outcome measures, such as those listed below:

- *Annoyance* /152/ is the most commonly cited outcome of disturbance by noise. Indeed, in the BRE study referred to earlier /224/, neighbor noise caused annoyance in 72% of those who reported hearing it and was considered a nuisance by 73% of those who heard it. The physical stimulus of noise, or its loudness, alone cannot explain individual differences in reactions to noise and generally accounts for only 10% to 25% of the variability in self-reported annoyance /143/. Indeed, research has shown that people are more annoyed by noises that they feel are avoidable or unimportant, such as doors banging, or that are emotive or make them feel afraid, such as children crying or loud arguments /230/. A French study dealing specifically with domestic noise revealed similar results, with the most annoying noises being described as loud, not normal, possible to avoid, and happening during the night /221/. Furthermore, preventability /142/ or misfeasance /231/ has long been thought to influence the level of annoyance experienced. It can thus be seen that the level of annoyance experienced in response to noise is moderated by the attributions of those hearing it, namely, attributions of the significance of the noise and attributions that are given to the person making the noise and their intentions /221/.
- *Activity disturbance* is an important effect of exposure to noise. This is particularly true because the amount of activity disturbance will likely mediate the level of annoyance that is experienced. Domestic activities, such as sleeping, resting, and listening to the television or radio, are those most commonly disrupted /224/, although noise may also restrict the use of parts of the house or garden, prevent windows or doors from being opened, and cause distraction when reading, writing, or having a conversation. Further evidence has shown that people use private gardens and parks less when there is too much noise /232/.
- *Sleep disturbance*, or reduced quality of sleep, is another commonly reported outcome of exposure to unwanted noise and may occur when the affected people are not even aware of it. Noise is especially disturbing at night when background noise levels are lower and sleep can be disturbed by even a very quiet sound, particularly if it has meaning for the listener. Raw and Hamilton /229/, for instance, cite a study in which 12.6% of flat dwellers complained that noise from neighbors disturbed their sleep. Sleep is a physiological necessity, which if insufficient, can have an adverse impact on health and well-being and may also have a moderating effect on other variables, such as annoyance. For example, partial sleep deprivation can impair performance on prolonged repetitive work and result in daytime sleepiness and irritability /229/. Furthermore, it seems that complete physiological habituation to sleep-disturbing noise does not occur, even after many years of exposure /233/.

- *Emotional response to noise* is a further outcome variable that must be considered if we are to have an adequate understanding of the subjective nature of the effects of noise. Unwanted noise can elicit a number of emotional reactions, including anger, fear, or depression. The overall effect of the noise is likely to depend to some extent on which of these reactions is experienced. Previous research has shown, for example, that more annoyance is experienced when the noise makes the individual feel fearful /156/. Furthermore, it is likely that noise that impairs a person's well-being will be more prejudicial to health than a noise that merely causes mild irritation.

Two relatively discrete types of emotional response to noise emerged in the BRE national noise attitude survey /224/. The first type involves more outwardly directed aggression, characterized by feelings of annoyance, aggravation, bitterness, and anger toward the source of the noise, whereas the second involves a more inward reaction, evoking such emotions as tension, anxiety, and pressure. In addition, there may be an important sex difference in the type of emotional response experienced, with the former being more commonly reported by men and the latter by women /224/. Possibly, however, this difference is a reflection of the study design.

Socio-Demographic and Environmental Factors

Although the evidence on the effects of socio-demographic variables is equivocal, previous studies /234/ have shown that age, for instance, can affect the likelihood of disturbance from neighborhood noise in general and from some specific noise sources. For example, the age group comprising 25- to 34-year olds is most likely to be annoyed or disturbed by noise from human voices, from radio/TV/hi-fi, from animals, and from vehicles, with the over-65-year age group being the least bothered by neighborhood noises.

Various environmental factors may have the potential to influence the effect of domestic noise. These include the following:

a) various aspects of the type of housing;
b) the number of years living at the address;
c) the extent of household insulation;
d) the type of tenure;
e) the location of the property;
f) the number of people living in the household;
g) general neighborhood satisfaction;
h) the state of repair of the property; and
i) the complainant's relation with the offending neighbor(s).

For example, occupants of all types of houses, but semi-detached in particular, are less likely than those living in flats to hear noise from neighbors, and in addition are less bothered by the noises that they do hear /235/. The latter finding indicates that flat dwellers are at high risk from the adverse health effects of noise, particularly as they are likely to be exposed to both airborne noise (for example, hi-fi/TV/talking/shouting) from all neighboring flats and impact noise (for example, footsteps/doors banging/light switches/electric sockets) from above. Furthermore, in flats, noise from above is ranked more disturbing than noise from below /236/, but it is suggested that this occurs simply because more noise emanates from the first source. In the study by Raw and Oseland /236/, noise from above was found to be significantly more disturbing when four or five persons, as opposed to one person alone, occupied the upstairs flat; the presence of dogs in the flat above also increased disturbance.

The type of tenure also has an important effect on the incidence of disturbance by noise, with 9% of those who fully own their own home being disturbed, in comparison with 19% of those renting from a LA /234/.

Then, quite clearly, certain demographic subgroups are more at risk than others for disturbance by neighborhood noise and, therefore, for the adverse effects associated with such disturbance. Those at particularly high risk, especially in the summer, are characterized as belonging to the younger- to mid-age group (25 to 34 years), with children, living in an attached property, particularly flats, rented from a LA /237/. In fact, the incidence of bother for this group is seven times higher than that for the low risk group comprising the upper age brackets with no children present, living in a property that is owned outright /234/.

Personal Characteristics

- *Perceived control*, according to Cohen and Spacapan /28/, 'has been implicated as a central determinant of noise on both behavior and health'. Graeven /238/, for instance, found that residents reporting an ability to control noise in their environment were less annoyed than those reporting no control. In this context, the personality construct 'locus of control' is important. Individuals with an external locus of control are those who attribute outcomes to the actions of others, whereas individuals who believe that outcomes are determined by their own behavior have an internal locus of control. Research has shown that locus of control can moderate reactions to noise. For example, Pulles et al. /239/ reported that individuals with an external locus of control had higher scores on annoyance, although no significant interaction with noise level was found.
- *Coping with the noise*, or rather the strategy employed by an individual in his/her attempts to cope with the noise, has been shown to have an impact on subjective health outcomes /240, 241/. More specifically, there are three basic coping styles:

1. problem-focused/action-directed (such as closing windows or doors to reduce the level of noise or asking the person responsible to reduce the noise exposure);
2. denial/avoidance (such as pretending that the noise does not exist or that it is not bothersome); and
3. palliative/comforting cognitions (trying to escape the effects of noise using alcohol or sleeping tablets, or telling oneself that the noise is not as bad as imagined).

According to van Kamp, a problem-focused/ action-directed coping style is negatively related and avoidance is positively related to the prevalence of health complaints. Further-more, an evasive strategy is associated with a significantly higher degree of annoyance.

- *Noise sensitivity* is a concept that was invoked to explain the considerable difference in noise tolerance between individuals at a given level of noise exposure (for example /121/). This concept has proved difficult to define. According to Job /242/, however, 'noise sensitivity refers to the internal states (be they physiological, psychological [including attitudinal], or related to life style or activities conducted) of any individual that increase their degree of reactivity to noise'. Noise sensitivity is important because the health effects of noise have been found to correlate more closely with reaction than with actual noise exposure.

According to the 1999 NSCA National Noise Survey /243/, many Environmental Health Officers (EHOs) believe that the high number of noise complaints received in recent years may largely be due to an increase in sensitivity to noise. They believe that as our capacity to make noise has increased, tolerance has decreased. 'Higher expectations of quiet, incompatible lifestyles with neighbors and selfish attitudes' are perceived by EHOs as the main reason for the increase in noise complaints, with 71% believing that the public has unrealistic expectations about noise.

Noise Characteristics

The source of the noise is, in itself, likely to have an impact on such outcome measures as annoyance, activity disturbance, and emotional response. The types of domestic noise that are most likely to elicit an adverse reaction are those that:

a) are loud, continuous and apparently indefinite;
b) are considered unnecessary or are due to thoughtlessness or lack of consideration;
c) are of unknown duration or have continued for longer than expected;
d) are of uncertain cause or source; and
e) are emotive or frightening /224/.

According to the 1991 BRE study, of all the sources of domestic noise, people are most likely to object to barking dogs, closely followed by banging doors, noise from a radio, TV or hi-fi, and human voices /244/. The NSCA survey in 1994 /244/ identified amplified music as the most common cause of complaint for two thirds of LAs, closely followed by barking dogs, a finding that was replicated in their 1999 survey /243/. This finding is in agreement with an earlier study /150, 245/, which found that two-thirds of complaints to LAs are about noise from music (34%) or barking dogs (33%). Noise from domestic activities and human voices, whilst disturbing, give rise to fewer complaints, which may largely be because such sounds are seen as somewhat unavoidable.

Other characteristics of the noise are also important. For example, intermittent noise, a defining characteristic of much domestic noise, is particularly disturbing and is recognized as a cause of psychological stress and sleep disturbance /246/. Other factors, such as the time of day that the noise occurs and the duration of each occurrence, may also moderate its effect. For instance, for all noises, including neighbor noise, there is a pattern whereby relatively little nuisance is experienced early in the morning, with rising levels during the day peaking during the evening, especially between 10:00 p.m. and midnight when people are trying to fall asleep, and then falling again late at night /150, 234, 235, 237/. Additionally, in the study by Levy-Leboyer and Naturel /221/, noise was considered normal in 42% of the cases when it occurred during the day, in comparison with only 24% of the cases when it occurred between 10:00 p.m. and 8:00 a.m. Furthermore, noise is considered normal more frequently when it does not last very long. This point is important because noise becomes more annoying the less it is considered normal. One can surmise, therefore, that noise causes more annoyance and is more likely to be prejudicial to health when it occurs at night and when it lasts a long time.

CONCLUSIONS

The evidence for the effects of environmental noise on health is strongest for annoyance, sleep and performance, and cognitive performance in children. Occupational noise exposure also shows an association with raised blood pressure. Dose-response relations can be demonstrated for annoyance and, less consistently, for blood pressure. The effects of noise are strongest for outcomes that, like annoyance, can be classified under 'quality of life' rather than illness. What such effects lack in severity is made up for in the numbers of affected people, as these responses are very widespread.

So much of the world is now assailed by environmental noise that finding truly tranquil, quiet areas for comparison with noisy areas for research purposes and restoration is becoming difficult. Such quiet areas may be beneficial in reducing stress and in providing physical and psychological restoration. A positive health virtue to quiet must be explored.

It may be that the risk of developing mental or physical illness attributable to environmental noise is quite small, although it is too soon to be certain of this in terms of the progress of research. Part of the problem is that the interaction between people, noise, and ill-health is complex. Humans are not usually passive recipients of noise exposure and can develop coping strategies to reduce the impact of high-noise exposure. If people don't like noise, then they may take action to avoid it by moving away from noisy urban environments or, if unable to move away, then they can develop coping strategies. Active coping with noise may be sufficient to mitigate any ill-effect. A perception of control over the noise source may reduce the threat of noise and the belief that it can be harmful. On the other hand, a perception of lack of control over noise may increase any potential harm to health. The latter may be true for those who are already ill or under stress, for whom additional noise may be more difficult to tolerate or ignore. In a situation in which many areas of life are not under the individual's control, noise may act as an indicator of multiple other stressors or threats. It may also be that noise is more harmful to health in situations in which several stressors interact, and the overall burden may lead to chronic sympathetic arousal or to states of helplessness. This aspect may be true in urban environments that have combinations of social and environmental stressors, where communities are already battling with other multiple disadvantages. This area requires further research. Thus, ill-health associated with chronic noise exposure may be restricted to persons in certain situations and not universally present in all those who are exposed to environmental noise. Relatively little field research on examining multiple stressors has been carried out.

Adaptation to long-term noise exposure needs further study. Most individuals who are exposed to chronic noise, for instance from major airports, seem to tolerate it. Yet, questionnaire studies suggest that high levels of annoyance do not decline over time, and although sleep disturbance seems relatively little in field studies of aircraft noise and sleep, heart-rate responses to aircraft noise during sleep do not habituate over time. Does this lack of habituation represent a failure of long-term adaptation, potentially harmful to health, or is it a reflection of normal bodily reactivity to everyday stressors? Another possibility is that adaptation to noise is only achieved at a cost to health, a cost to coping. Evans et al. /192/ found that maintaining task performance in noisy offices was associated with additional physiological effort and hormonal response. McEwen /247/ coined the term 'allostasis' to describe the body's response to chronic stress, in which there is a patho-physiological cost to maintaining health. The possibility of such a response to noise and other environmental stressors requires further enquiry.

Undoubtedly a need exists for further research to clarify this complex area. This research should include better measurement of noise exposure, better measurement of health outcomes, and more attention paid to considering confounding factors and the effect modifiers in the association between noise and health. A further problem to be tackled is the replication in field studies of the results from laboratory studies. Often strong effects are found in laboratory studies where the subjects are exposed to novel noises. Demonstrating similar effects in the less-controlled surroundings of field studies, where, in addition, some adaptation to noise may have occurred, can then be difficult. More emphasis should also be placed on studies combining different environmental stressors with noise and including complementary health outcomes (for example, endocrine and performance measures in occupational studies). Moreover, a greater emphasis should be placed on field studies using longitudinal designs with careful choice of samples to avoid undue bias related to prior noise exposure. A concentration on studying vulnerable groups within the population may yield the most important results.

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