The non-auditory health effects of noise exposure

Les effets non-auditifs de l'exposition au bruit sur la santé

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Noise is a prominent feature of the environment including noise from transport, industry and neighbours. This paper reviews the effects of environmental noise on non-auditory aspects of health. Exposure to transport noise disturbs sleep in the laboratory, but not generally in field studies where adaptation occurs. Noise interferes in complex task performance, modifies social behaviour and causes annoyance. Studies of occupational and environmental noise exposure suggest an association with hypertension whereas community studies show only weak relationships between noise and cardiovascular disease. Aircraft and road traffic noise exposure are associated with psychological symptoms and psychotropic medication use but not with clinically defined psychiatric disorder. In both industrial studies and community studies noise exposure is related to raised catecholamine secretion. In children, chronic aircraft noise exposure impairs reading comprehension and long term memory and may be associated with raised blood pressure. Further research is needed examining coping strategies and the possible health consequences of adaptation to noise.

Le bruit est une donnée importante de l'environnement qui comprend les bruits des transports, de l'industrie et du voisinage. Cet article présente les effets non-auditifs du bruit de l'environnement sur la santé. L'exposition en laboratoire au bruit des transports gêne le sommeil, ce qui n'est généralement par le cas lors d'études sur le terrain pour lesquelles une adaptation apparaît. Le bruit agit sur les performances lors de tâches complexes, modifie le comportement social et provoque des désagréments.
Des études portant sur l'exposition au bruit dans l'environnement et au travail suggèrent une corrélation avec l'hypertension tandis que des études sociétales ne montrent qu'une faible coïncidence entre le bruit et des maladies cardiovasculaires. Les expositions aux bruits des avions et du trafic routier sont associées à des symptômes psychologiques et à l'utilisation de psychotropes mais sans définition clinique de désordres psychiatriques. Dans des études conjointes en milieu industriel et sur la société, la durée d'exposition au bruit est corrélée à l'augmentation de sécrétion de catécholamine. Chez les enfants, une exposition chronique au bruit des avions diminue la compréhension de la lecture et la mémoire à long terme et peut être corrélée à un accroissement de la pression artérielle. Une recherche future nécessitera d'examiner les stratégies de couronnement et les conséquences possibles de l'adaptation au bruit.

Noise, defined as "unwanted sound" is perceived as an environmental stressor and nuisance, intruding into personal privacy and causing annoyance and decline in quality of life. There is controversy as to whether noise causes illness. If noise does cause ill-health, what might be the mechanism ? It is generally believed that noise disturbs activities and communication, causing annoyance. In some cases annoyance may lead to stress responses, then symptoms and possibly illness [1]. Alternatively, noise may influence health directly and not through annoyance. The response to noise may depend on characteristics of the sound including intensity, frequency, complexity of sound, duration (whether intermittent or continuous) and the meaning of the noise.

Non-auditory effects of noise, as dealt with in this paper, can be defined as "all those effects on health and wellbeing which are caused by exposure to noise, with the exclusion of effects on the hearing organ and the effects which are due to the masking of auditory information (i.e communication problems)" [2]. This paper describes the research on noise exposure and sleep, social behaviour, cardiovascular disease, psychiatric disorder and annoyance. This review paper has been developed and updated from earlier reviews examining the need for new research in environmental noise [3,4].

Non-Auditory Effects of Noise

Noise and Sleep Disturbance

There is both objective and subjective evidence for sleep disturbance by noise [5,6,7].

Exposure to noise during sleep has shown sleep disturbance proportional to the amount of noise experienced in terms of an increased rate of changes in sleep stages and in number of awakenings. 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. In the laboratory, there

was no habituation during 14 nights of exposure to noise at maximum noise level exposure [8]. 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. In fact, there is a low association between outdoor noise levels and sleep disturbance.
In the Civil Aviation Authority Study (1980) [9] 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 UK airports, sleep disturbance was studied in relation to a wide range of aircraft noise exposure over 15 consecutive nights [10]. Although there was a strong association 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 already adapted to aircraft noise exposure, this study is also likely to be closer to real life than laboratory studies with subjects newly exposed to noise.

Road traffic noise at 50-60 dB(A) maximum increases the time taken to fall asleep. In particular the number of noise events seems important in this effect [11]. The first third of the night is the time most vulnerable to sleep disturbance. Living less than 20 metres from a busy road has been found to predict insomnia in a study of Japanese women adjusting for many relevant confounding factors [12].

Noise exposure during sleep may increase blood pressure, heart rate and finger pulse amplitude as well as body movements [13]. Not only may noise affect sleep but it may 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 [5]. Studies on noise abatement, show that by reducing indoor noise level, the amount of REM sleep and slow wave sleep can be increased [14]. It does seem that although there may be some adaptation to sleep disturbance by noise, complete habituation does not occur, particularly for heart rate.

Noise Exposure and Performance

There is good evidence, largely from laboratory studies, that noise exposure impairs performance [15]. 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 [16]. The effects of "irrelevant speech" are independent of the intensity and meaning of the speech. The susceptibility of complex mental tasks to disruption by "irrelevant speech" suggests that reading, with its reliance on memory, may also be impaired [17]. This research seems relevant to office workers, especially those working in open plan offices.

Perceived control over and predictability of noise has been found to be important in determining effects and after-effects of noise exposure. Glass & Singer [18], found that tasks performed during noise were unimpaired but tasks that were performed after noise had been switched off were impaired. This impairment was reduced when subjects were given perceived control over the noise. Indeed even anticipation of a loud noise exposure in the absence of real exposure may impair performance and an expectation of control counters this effect [19].

Noise and Memory

There have been several studies suggesting that noise slows rehearsal in memory [20] and may influence processes of selectivity in memory and attention. It may also influence the choice of strategies for carrying out tasks [2].

Noise and Social Behaviour

This is a very important area of noise research because many human activities involve social interaction which may relate not only to communication but also to health. Many of the effects of noise on social life reflect direct effects of noise on communication. There is also evidence that noise may reduce helping behaviour, increase aggression and reduce the processing of social cues seen as irrelevant to task performance [21].

Noise and Cardiovascular Disease

Physiological Responses to Noise Exposure`

Noise exposure causes a number of predictable short-term physiological responses mediated through the autonomic nervous system. Exposure to noise causes physiological activation including increase in heart rate and blood pressure, peripheral vasoconstriction and thus increased peripheral vascular resistance. There is rapid habituation to brief noise exposure but habituation to prolonged noise is less certain [14].

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 [22] (see Table 1). Many occupational studies have suggested that individuals chronically exposed to continuous noise 85 dB or greater had higher blood pressures than those not exposed to noise [23,24,25]. In many of these studies noise exposure has also been an indicator of exposure to other factors, both physical and psychosocial, which are also associated with high blood pressure. Unless these other risk factors are controlled, spurious associations between noise and blood pressure may arise.

A recent pioneering longitudinal industrial noise study has shown that noise levels predicted raised systolic and diastolic pressure in those doing complex but not simple jobs [26]. This study also suggests a link between occupational noise exposure and mortality risk. Occupational noise exposure has also recently been linked to greater risk of death from motor vehicle injury [27] and is among the factors predicting disability retirement [28].

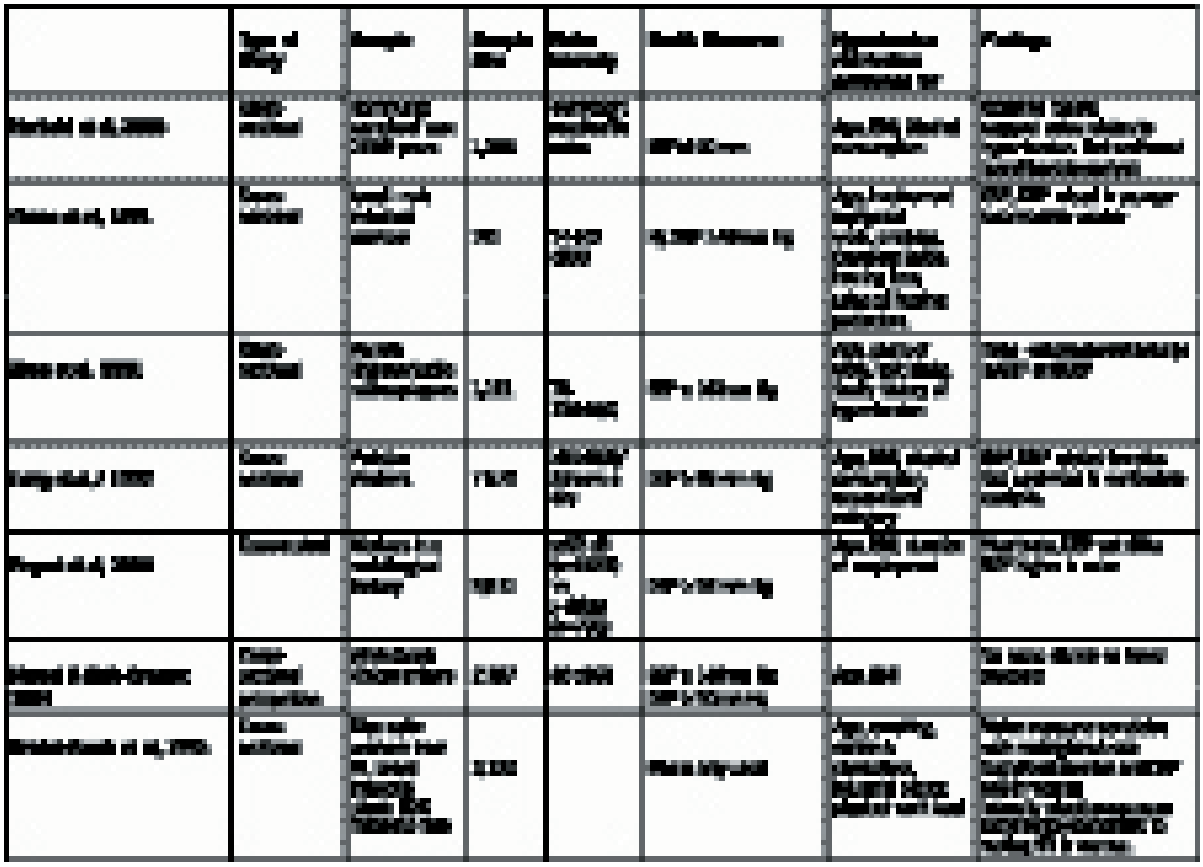

Table 1 : Occupational Studies of Noise Exposure and Blood Pressure

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 [29] although this has not been convincingly proved. Noise annoyance and noise exposure have recently been found to have additive effects on serum cholesterol level in young men exposed to industrial noise [30]. This might be another way in which noise annoyance might be linked to cardiovascular disease.

Noise and cardiovascular disease in the community

Aircraft noise exposure around Schiphol Airport has been related to more medical treatment for heart trouble and hypertension, more cardiovascular drug use and higher blood pressure [31] even after adjustment for age, sex, smoking, height/weight, and socio-economic differences. The evidence of the effects of noise on coronary risk factors has not been especially consistent : effects of noise have been shown on systolic blood pressure (but not diastolic pressure), total cholesterol, total triglycerides, blood viscosity, platelet count and glucose level [32]. However, a recent Swedish study found that the prevalence of hypertension was higher among people exposed to time weighted energy averaged aircraft noise levels of at least 55dB(A) or maximum levels above 72dB(A) around Arlanda airport [33]. In summary, there is some evidence from community studies that environmental noise is related to hypertension and there is also evidence that environmental noise may be a minor risk factor for coronary heart disease (Relative risk 1.1-1.5) [34,35].

A sudden intense exposure to noise may stimulate catecholamine secretion and precipitate cardiac dysrhythmias. However, neither studies in coronary care units of the effect of speech noise nor noise from low altitude military flights on patients on continuous cardiac monitoring caused changes in cardiac rhythm [36].

Endocrine Responses to Noise

Exposure to high intensity noise in industry has been linked in some studies to raised levels of noradrenaline and adrenaline [37,38]. In one study catecholamine secretion decreased when workers wore hearing protection against noise. Some studies, but not all, have shown raised cortisol in relation to noise [39].

There have been some studies in children : Hygge [40] found increased adrenaline and noradrenaline in children exposed to chronic aircraft noise. Evans et al in a study of Alpine traffic noise found that children exposed to noise levels of greater than 60dB(A) compared to less than 50dB(A) had raised urinary overnight cortisol levels, but no differences in urinary noradrenaline and adrenaline [41]. The general pattern of endocrine responses to noise is commensurate with noise as a stressor, exciting short term physiological responses.

Noise and Psychiatric Disorder

It has been postulated that noise exposure creates annoyance which then leads on to more serious psychological effects. This pathway remains unconfirmed, rather it seems that noise causes annoyance, and independently, mental ill-health also increases annoyance. A more sophisticated model [42,43] incorporates the interaction between the person and their environment. In this model the person readjusts their behaviour 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 etc) and coping (the ability to alter behaviour to deal with the stressor). This model emphasises that dealing with noise is not a passive process.

Noise Exposure and Psychological Symptoms

Symptoms reported among industrial workers regularly exposed to high noise levels in settings such as weaving mills [44], jet aircraft test beds [45], schools [46], and factories [47] include nausea, headaches, argumentativeness and changes in mood and anxiety. More illness-related absenteeism [48] and social conflicts at work and home [49,50] have been found in noisy rather than quiet industries. Many of these industrial studies are difficult to interpret, however, because workers were exposed to other stressors such as physical danger and heavy work demands, in addition to excessive noise.

Community studies of noise and symptoms

Environmental noise experienced outside work settings, though 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 [51,52,53,21]. An explicit link between aircraft noise and symptoms emerging in such studies raised the possibility of a bias towards over-reporting of symptoms [54]. Notably, a study around three Swiss airports [55], did not mention that it was related to aircraft noise and did not find any association between the level of exposure to aircraft noise and symptoms.

Noise and Psychiatric Hospital Admissions

Early studies found associations between the level of aircraft noise and psychiatric hospital admission rates, both in London [56] and Los Angeles [57,58]. Better designed later studies [59] found little consistent association between [60], aircraft noise levels and higher admission rates. Admission rates seemed to follow non-noise factors more closely ; the effect of noise, if any, could only be moderating that of other causal variables, although Kryter [61], in a re-analysis of this data, claimed a positive association. It seems likely that the route to hospital admission is influenced by many psychosocial variables, which are more potent than exposure to noise. Therefore, whether or not noise causes psychiatric disorder would be more suitably answered by studying a community sample.

Noise Exposure and Psychiatric Morbidity in the Community

In the West London Survey of Psychiatric Morbidity [62], no overall relationship was found between aircraft noise and the prevalence of psychiatric morbidity using various indices of noise exposure. However, there was an association between noise and psychiatric morbidity in two subgroups : "finished full time education at aged 19 years +"; and "professionals". The authors [62] 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 association between road traffic noise exposure and psychiatric disorder has also been examined in a population unlikely to have been selected by noise exposure, (which may be the case around a well-established airport such as Heathrow). In longitudinal analyses in the Caerphilly Study no association was found between the initial level of road traffic noise and psychiatric disorder, even after adjustment for socio-demographic factors and baseline psychiatric disorder [63]. However, there was a small non-linear association of noise with increased anxiety scores [63].

Psychosocial wellbeing 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 [8,64]. Exposure to higher levels of military aircraft noise around Kadena airport in Japan was related in a dose response relationship to depressiveness and nervousness [65,66]. In a large British study road traffic noise was weakly associated with a 5 item mental health symptoms scale adjusting for age, sex, income and length of residence [67]. There was no interaction between noise exposure and noise sensitivity in determining symptoms as has also been reported in other studies [68]. Overall, environmental noise seems to be linked to psychological symptoms but not to clinical psychiatric disorder. However, there may be a link to psychiatric disorder at much higher noise levels.

The use of health services has also been taken as a measure of the relationship between noise and psychiatric disorder. Grandjean [55] reported that the proportion of the Swiss population taking drugs was higher in areas with high levels of aircraft noise. In this study, there was also an association between the rate of contact with general practitioners and level of noise exposure. In the Heathrow study [69], none of the indicators of health service use showed any clear trend in relation to levels of noise.

Noise Sensitivity and Vulnerability to Psychiatric Disorder

Noise sensitivity, based on attitudes to noise in general [70,71], is an intervening variable which explains much of the variance between exposure and individual annoyance responses [72,73]. Individuals who are noise sensitive are also likely to be sensitive to other aspects of the environment [74,75]. This raises the question whether noise-sensitive individuals are simply those who complain

more about their environment. Certainly there is an association between noise sensitivity and neuroticism [76], although it has not been found in all studies. On the other hand, Weinstein [77] hypothesised that noise sensitivity is part of a critical-uncritical dimension, showing the same association as noise sensitivity to measures of noise, privacy, air pollution, and neighbourhood reactions. It may be that noise sensitivity represents both these aspects : being critically discriminating about the environment and having high neuroticism scores.

Noise sensitivity has also been related to current psychiatric disorder [74,78] including phobic disorders and neurotic depression [74]. 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.

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 [79]. Noise is also seen as intrusive into personal privacy, while its meaning for any individual is important in determining whether that person will be annoyed by it [80].

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 [81,82]. In both traffic and aircraft noise studies, noise levels have been found to be associated with annoyance in a dose-response relationship [83,84,85]. 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 most disturbed by aircraft noise [82] while traffic noise, if present at night, is most disturbing for sleep.

Acoustic predictors of noise annoyance in community surveys

One of the primary characteristics affecting the unwantedness of noise is its loudness or perceived intensity. Loudness is comprised of the intensity of sound, the tonal distribution of sound and it's duration. The evidence is mixed on the importance of the duration and the frequency components of sound in determining annoyance and also the number of events [86]. High frequency noise has been found to be more annoying than low frequency noise [87]. McKennell [88] found that the short duration of Concorde flights over London appeared to offset somewhat the increased perceived loudness of Concorde compared to conventional jet aircraft. Correlations between noise and annoyance are lower for impulse than continuous noise [70].
This 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 [70]. Vibrations are perceived as a complement to loud noise in most community surveys of noise and are found to be important factors in determining annoyance, particularly because they are a commonly experienced through other senses as well as hearing [88]. There is no evidence that ambient noise has a significant effect on noise annoyance related to target noises such as aircraft, road traffic, railway or impulse noise [89]. The evidence on the association of noise and socioeconomic position is mixed ; if anything high socioeconomic position is related to higher levels of annoyance, perhaps because of greater expectations from the environment [90].

Fields [91] found that after controlling for noise level, noise annoyance increases with fear of danger from the noise source, sensitivity to noise, the belief that the authorities can control the noise, awareness of the non-noise impacts of the source and the belief that the noise source is not important.

Noise and Non-Auditory Health Effects in Children

Children may be more susceptible to environmental stress than adults for a variety of reasons including : less cognitive capacity to understand environmental issues and anticipate stressors and less well-developed coping repertoires [92,93]. Noise effects on children's school performance are not considered here as they are reviewed elsewhere in this journal [94].

Combined effects of noise exposure and other stressors

Noise effects on health may be augmented by, or may augment in turn, the impact of other stressors on health. Stressors may act 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 relationships [95]. There has been much emphasis on laboratory studies without considering that 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 [96]. In a laboratory based experiment an interaction was found between having a cold and noise exposure on simple reaction time [97]. There was little difference between healthy and cold subjects'performance 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 main effects of noise (e.g. detection of repeated numbers task) or effects of colds 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 morning adrenaline secretion [98] - but these were only 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 [99].

Field studies suggest that the effects of multiple stressors have greater combined effects than simply summing individual stressors [100]. It might be the case that noise will show more effects on health in individuals already exposed to other stressors. There have been few studies that have attempted to examine the effects of multiple environmental stressors [92]. These might include other physical stressors (e.g. air pollution, poor housing conditions), psychosocial stressors (e.g. crowding, social isolation, fear of crime, perception of lack of control over the environment) and 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 which is a nuisance to other neighbours'[101], is now the greatest source of noise nuisance and public complaint. According to the national noise attitude survey conducted by the Building Research Establishment (BRE) in 1991 [102], environmental noise spoils the home life of one in three people to some extent, and totally spoils the home life of one in a hundred. However, despite the prevalence of domestic noise complaints and the adverse impact on those involved, research in the field is limited and there remains a dearth of evidence on the effects of domestic noise.

Domestic noise certainly causes annoyance, activity disturbance and sleep disturbance. It may also cause emotional responses, or precipitate emotional responses which may be severe. A more detailed review of the available literature on domestic noise and health is reported elsewhere [4].

Conclusions

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

So much of the world is now assailed by environmental noise, it is becoming difficult to find truly tranquil, quiet areas for comparison with noisy areas for research purposes and restoration. Such quiet areas may be beneficial in reducing stress and providing physical and psychological restoration – a positive health virtue to quiet needs to 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 a complex one. Humans are not usually passive recipients of noise exposure and can develop coping strategies to reduce the impact of noise exposure. If people don't like noise they may take action to avoid it by moving away from noisy environments or, if they are unable to move away, by developing coping strategies. Active coping with noise may be sufficient to mitigate any ill-effects. Perception of control over the noise source may reduce the threat of noise and the belief that it can be harmful. It may also be that noise is more harmful to health in situations where several stressors interact and the overall burden may lead to chronic sympathetic arousal or states of helplessness.

Adaptation to long term noise exposure needs further study. Most people 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. Another possibility is that adaptation to noise is only achieved with a cost to health. Evans et al [103] found that maintaining task performance in noisy offices was associated with additional physiological effort and hormonal response.

Undoubtedly, there is a need for further research to clarify this complex area including better measurement of noise exposure, and health outcomes. Moreover, there should be a greater emphasis 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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