Sozial- und Präventivmedizin Médecine sociale et préventive 19, 169–175 (1974)

Environmental Noise Nuisance

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Some effects of noise are clearly harmful in that they impair human health, the obvious example being that of hearing damage which results from excessive exposure to intense sound levels. In the U.K. alone it has been estimated [ref. 13] that some 600,000 people work in noise levels which will eventually damage their hearing ability. Perhaps somewhat surprisingly, few of these people are concerned about the noise or aware of risk, largely because they have accepted noise as a necessary part of their working environment. It is ironical that far greater numbers of people are conciously dissatisfied with noise exposure, which, in physical terms, is in orders of magnitude smaller by comparison. For example, roughly 4 million people in the U.K. live in homes close to roads, the noise from which they consider to be unacceptable [ref. 13].

What is the reason for this curious disparity? To answer this question we must examine the mechanisms of noise nuisance and the reasons why some sounds are tolerated, others are not.

The phrase "environmental noise nuisance" is used here to describe those general community noise problems which do not involve any obvious or immediate hearing risks, according to currently accepted criteria. This is not to say that no health hazards are involved. Whether they are depends to some extent upon the definition of health, but accepting the World Health Organisation position that "health is a state of complete physical, mental and social well-being and not merely an absence of disease or infirmity", there can be little question that many "environmental noise" situations endanger health; the question is, how can the risk be measured and how bad is it?

Some idea of the extent of noise nuisance can be obtained from the results of a survey conducted in Central London in 1961 [ref. 8] where it was found that noise was one of five major factors which people felt degraded their living conditions. The others were other forms of pollution, the amount of traffic on the roads, local amenities and the type of people who shared their neighbourhood!

Table 1
Noises which disturb people at home, outdoors and at work

Description of noise	% of people disturbed at home		at work
Road traffic	36	20	7
Aircraft	9	4	1
Trains	5	1	0
Industry/construction	7	3	10
Domestic appliances	4	–	4
Neighbours' impact noise (knocking, walking, etc.)	6	–	-
Children	9	3	-
Adult voices	10	2	2
Radio/TV	7	1	1
Bells/Alarms	33	1	1
Pets	3	–	–

The annoyance caused by environmental noise is the most important criterion for assessing tolerance limits. The effects of annoyance are the basis for noise abatement procedures.

In a more recent survey of people living in the high noise area near London's Heathrow Airport, noise ranked second only to the risk of road accidents in a list of the most troublesome features of local living [ref. 10]. If we look more closely at particular sources of irritation we find that transportation is the major contributor and that noise nuisance is more of a problem at home than at work or out of doors generally. This is shown in table 1 [from ref. 8].

The sound intensities responsible for this dissatisfaction are literally several orders of magnitude less than those found in factories and other noisy work places, typically by factors of 10^{-3} or 10^{-4} (30–40 dB less). Indeed people in the home may be irritated by sounds which may not even register on a sound level meter.

Effects of Environmental Noise

The phrase "Community Response" (to noise), frequently found in the literature, has been purposely avoided here because it implies some positive action on the part of the community. Whilst such action can and frequently does occur, noise nuisance does not necessarily induce overt response; indeed on the vast majority of occasions, it does not. In these cases we have to consider the private feelings and responses within the individual which usually are communicated to no one. Many terms are used to describe such responses and attributes of the sounds themselves. Examples are loudness, noisiness, annoyance, disturbance, dissatisfaction and so on. In general there are no accurate definitions of these expressions and consequently a review of the literature, even in one language, is somewhat confusing. The difficulty becomes acute when international comparisons are necessary. To minimise such difficulties here the effects of noise upon people are divided into two categories: direct and indirect. The distinctions between these will be clarified below.

Although the matter will be considered further at a later point, some reference to the question of noise measurement is necessary at this point. Sound intensity is the rate at which acoustic energy arrives within a certain (unit) area; this may vary with time, sometimes rapidly. The decibel scales of intensity level and sound pressure level are convenient measures of physical acoustic energy. The subjective quantities loudness and loudness level (where the latter is in decibel form) are related to average human perception

of sound "magnitude". Because of the characteristics of the ear, this is dependent upon frequency as well as intensity and numerous procedures exist for obtaining estimates of subjective loudness from physical noise measurements. The most convenient of these is the sound level meter A-scale which provides a direct estimate of loudness level. Readings upon this and similar scales are simply called Sound Levels. It is not necessarily true that sounds of equal loudness will cause the same effects. However, we may assume that whatever these effects are, they can only increase as sound level increases.

Direct Effects

The direct effects of noise involve its interference with human activity, and may be summarised as various forms of disturbance. Obviously some activities are more sensitive to noise than others so that the potential for disturbance depends upon what a person is doing. It is thus convenient to divide these activities into three groups:

(a) Activities which do not involve auditory reception of information.

These include many forms of mental or manual work or leisure activities. The disturbance potential of noise in these cases is related to its ability to attract attention to itself (and consequently to distract attention from the activity). In fact people adapt to surprisingly high levels of noise provided the sound level is relatively steady. Examples are the noise in noisy machine shops and the hum of ventilation equipment and the noise inside vehicles. Provided there is no requirement for verbal communication awareness of such sound is relegated to the subconscious. It is *changes* of sound level which are much more likely to be noticed, changes which inform the listener that something unusual is happening. Such changes may be increases or decreases in level. Things being turned off are just as likely to be noticed as things being turned on. The distracting capacity of changing sound in this sense varies little with absolute sound level. Thus, in a very quiet ambient environment, dripping taps, closing doors, footsteps and distant barking dogs are likely to distract. Yet in a home adjacent to a busy road the steady traffic may pass unnoticed. Only the particularly noisy trucks will stand out and attract attention. Although "non-auditory" activities are disturbed by changes in sound it should be recognised that these changes may not be measurable. Intruding sounds become noticeable when their level increases within 5 to 10 dB of the steady ambient noise at which point the combined sound level has increased by between 0.5 and 1.0 dB, an increment which could escape notice on a sound level meter scale.

Also some favourable qualities of steady noise should not be overlooked. Recognising that activities in this category are primarily sensitive to changes in level, distraction may be minimised by increasing the steady ambient component, for example by the introduction of ventilation fans or even artificial noise sources.

(b) Activities which do involve auditory reception of information.

There is no doubt that unwanted sound which is sufficiently intense to physically interfere with or mask wanted sound will constitute a disturbance. Perhaps the clearest finding of the many social surveys which have been performed is the significance of speech interference as a source of disturbance. Most "wanted sound" is in the form of speech although it certainly includes music and various kinds of warning signals. In our modern society perhaps it is not surprising that the most frequently reported disturbance concerns the interruption of TV or radio reception. By comparison with other noise nuisance problems, that of speech interference is relatively well understood [see for example ref. 7]. For steady state sounds the relationships between the physical characteristics of the sound and speed intelligibility are reasonably well documented and useful working criteria are available to guide design and planning in many architectural applications. Table 2 shows typical information [based on data taken from ref. 17].

For unsteady sounds the same relationships between noise and intelligibility probably apply provided sound levels do not change too rapidly. The question in such situations concerns when or how frequently wanted and unwanted sounds coincide. In the case of road traffic noise for example a resident will almost certainly be disturbed by every noisy truck when he is watching TV since this auditory activity is continous. Otherwise he may only be disturbed by noisy trucks when he is engaged in conversation. Clearly activities which involve, or even crucially depend upon, continuous aural communication are particularly sensitive to noise intrusion. The incidence of disturbance in such cases may be determined with some confidence from the data of table 2.

The previous statement regarding possible favourable effects of noise apply also with regard to speech privacy. In open plan offices, passenger vehicles and any spaces where people gather to converse, a moderate background noise level is necessary to prevent intrusion upon private conversation. Absence of such background noise actually suppresses conversation.

(c) Sleep.

Noise can prevent people from falling asleep and, if they are asleep, it can wake them up. Like most other effects of noise, sleep interference depends upon many circumstances, in this case including the depth of sleep, the characteristics of the noise and personal factors. In general the deeper the sleep, the lower the

Table 2
Maximum distance for comfortable conversation

Level dB(A)	Distance (m)	Quality of telephone communication
35	17	
40	10	
45	5.6	
50	3.2	Satisfactory
55	1.8	
60	1.0	Slightly difficult
65	.56	
70	.32	Difficult
75	.18	
80	.10	Unsatisfactory

noise sensitivity. Thus awakening thresholds are highest about ½ to 2 hours after falling asleep but decrease from then until morning awakening. Noise sensitivity is affected by the meaning attached to the sound, for example people are highly responsive to their own names. As in the case of distraction, awakening thresholds are more related to changes of sound level than to steady levels. It has been observed that women are more disturbance-prone than men and there is a marked increase in the tendency to be awakened with advancing age.

Indirect Effects

Disturbance in the present context does not necessarily imply a negative reaction on the part of the disturbed. Obviously noise intrusion may be accompanied by pleasant experiences; for example a noisy car may bring welcome visitors. In general however disturbing sounds are unwanted and are likely to evoke a negative response in the listener. These negative responses may take many forms, ranging from mild displeasure to violent anger. Such indirect effects must be described with reference to time since they may result not from one disturbance but from a series of disturbances over a period of time. Although it is difficult to summarise these effects by a single term, "annoyance" is perhaps an appropriate choice to describe the overall feeling of vexation caused by one or more noise disturbances. Also, even moderate annoyance may be accompanied by stress symptoms, that is a condition of physiological arousal controlled by the nervous system and involving the stimulation of various body organisms including the glands, viscera, heart and blood vessels. Endoctrinal fluids may be released into the bloodstream, blood vessels may be constricted leading to increases of blood pressure and pulse rate. Although there is little evidence to confirm the possibility it is clear that repeated or continuous stress of this kind could have long term debilitating effects including circulatory, digestive, metabolic, neurological and psychiatric difficulties.

From a psychological point of view the cumulative effect of repeated annoyance is to cause a general dissatisfaction with the situation which causes the noise. Ultimately the sufferer may resort to direct action to alleviate the problem by complaining, by organising public protest if appropriate, by moving away from the noise or by numerous other options.

Differences between people

The discussion so far has been characterised by frequent use of the words "may" and "might"; about noise nuisance little is certain, indeed most factors are very uncertain. In fact people differ very widely in their reactions to noise. In the noisiest of situations a small percentage of people are oblivious to the noise; conversely, in very quiet situations a small but finite number of people express severe displeasure. *Bryan* and *Tempest* [ref. 1] have argued that these groups represent the population at large, that people are either "sensitive" or "unperturbable". In fact it seems more probable that they represent the extremes of some unimodal distributions and evidence to support this view will be presented later.

Whatever the explanation, this very large variation between people has been the cause of a great deal of confusion in the area of environmental noise control. Considerable effort has been spent in the search for the natural laws linking physical noise exposure and its effects. In fact, because the effects are sensitive to many factors other than noise there is a distinct possibility that these laws will never be discovered.

Measurement of Cause and Effect

Figure 1 depicts a general cause-and-effect model of environmental noise impact derived from an analysis of the research literature [refs. 9 and 11]. The direct effects are shown as functions of noise exposure and activity and the indirect effects depend upon the disturbance and a set of intervening sociopsychological variables which are combined under the description of "sensitivity". These factors include the individual's personality, his experience and his attitude towards the source of the noise. In a sense they dictate whether the sound is wanted or unwanted. An example will clarify the importance of these factors. To listen to one's own radio is a pleasure; the sound of someone else's at a distance (and at a substantially lower sound level) is offensive. To predict how an individual will react to a radio one first needs to know whether or not he or someone else is using it. This one fact will probably outweigh all other considerations.

Such factors will always influence annoyance. In the case of aircraft noise, a particular noise nuisance which has been studied extensively, it has been found [ref. 15] that they include fear of crashes, socioeconomic status and education, opinions about the injustice of the noise, opinions about the importance

of the aircraft operations and a belief that the noise could be better controlled.

Figure 1

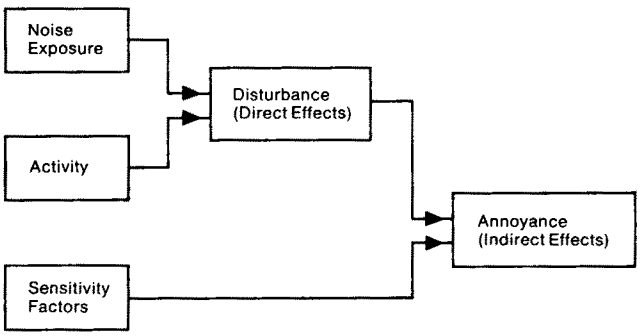


Figure 1 suggests that from statistical descriptions of both disturbance potential and the sensitivity factors, estimates might be made of probable annoyance reactions. Unfortunately this hypothesis cannot be tested at the present time. One reason is that, although the meaning of annoyance as used here can be defined with some precision, we cannot be certain that it can actually be measured. Firstly annoyance in this sense is a short-lived phenomenon induced by disturbance as and when it occurs. Any attempt to observe annoyance would undoubtedly influence its magnitude. The same must be said of attempts to simulate "real life" conditions in the laboratory. The direct effects of noise, distraction, speech interference, even sleep interference, can be studied in the laboratory or through controlled field experiments. Annoyance is a much more elusive effect which by its very nature is extremely sensitive to external influence.

Perhaps the only resort to which the experimenter may turn is that of the social survey. Various attitude scales have been developed to measure what has been termed annoyance but inevitably these are imperfect procedures which involve the subject's memory of typical disturbances. In effect these procedures measure some integrated combination of activity, disturbance and annoyance as defined herein. The resulting response scale invariably involves a certain degree of arbitrariness and is frequently highly specialised for the specific noise problem under study.

In order to establish relationships between noise exposure and "annoyance" the former must also be defined in quantitative terms. As noted previously we may assume that whatever the effect, the louder of two sounds will be the more adverse and in recognition of this basic premise considerable study has been made of methods for estimating loudness from spectral analysis of the sound. Some are extremely complex [refs. 3 and 4] whilst others can be read from a standard sound meter. In fact the practical differences between these scales are small and most researchers now accept that the convenient A-scale is adequate for estimating instantaneous loudness levels.

However sound levels do not remain constant and for periods of more than a few seconds it is necessary to account for the temporal variation of the sound. Intuition and laboratory experiments suggest that the acoustic characteristics which relate to disturbance and consequently annoyance, include intensity, frequency content and the manner in which these vary with time. Additional factors include discrete frequency components, impulsiveness, intermittency, abruptness of intensity changes and so on.

Intensity and frequency content are both accounted for by the sound level scale. Some of the other characteristics can be incorporated in numerous ways and a variety of composite noise exposure scales have been developed which combine them into a single number. What most of these scales share in common is an integration process to account for the repetitive or continuous nature of the sound. The precise form of the integration process depending upon the convenience with which the necessary data may be acquired. For example scales developed for the measurement of aircraft noise are based on the availability of a discrete set of values, one for each event and involve relationships of the form:

$$\text{Composite level} = \text{average level} + K \log (\text{No of events}) \quad (1)$$

The value of the constant K varies from scale to scale.

Others, originally designed for more complex sound histories which are not amenable to discrete analysis, are based upon convenience of measurements. The most straightforward of these is the equivalent continuous noise level L_{eq} given by

$$L_{eq} = 10 \log_{10} \frac{1}{T} \int_0^T 10^{L/10} \, dt \quad (2)$$

where L is the instantaneous sound level and T is the time period of interest.

In one attempt to account for the importance of fluctuations in sound level, equation (2) has been extended to account for the dynamic range of the level fluctuations. The result, known as Noise Pollution Level [ref. 14] is:

$$L_{NP} = L_{eq} + 2.56\,\sigma \quad (3)$$

Where δ is the standard deviation (in dB) of the fluctuation in level (2.56σ is the interdecile range for normally distributed levels). The logic behind this scale is apparent in the light of earlier discussions.

Correlation between Noise Exposure and Annoyance

In studying the problem of noise nuisance, most researchers have sought a direct correlation between

noise exposure levels, expressed in terms of various physical parameters, and "annoyance" expressed on some form of cumulative scale. Most studies to data have concentrated upon some particular aspect of the general noise nuisance problem; many for example, have been concerned specifically with the effects of aircraft and road traffic noise upon residential communities. As table 1 shows these two problems comprise a large proportion of total noise nuisance, at least in or near cities. This constrained sphere of interest restricts the range of activities and intervening sensitivity factors which influence nuisance with two important consequences. The first is that the correlation between noise and annoyance is higher than might be expected in a more general situation. However this advantage is largely offset by the second which is that the results have rather restricted applicability. Because different noise problems have been investigated independently, it is very difficult to relate the different results. This leads to serious practical difficulties in assessing the impact of noise environments where no particular noise source dominates.

Because of its particularly serious nature, aircraft noise has received more attention than other environmental noise problems and a relatively large body of survey research data has been compiled. Although many of the findings are of relevance to this problem only, some of the more general conclusions which are summarised in the remainder of this paper probably apply to a wider range of environmental noise nuisance [refs. 9, 11 and 12].

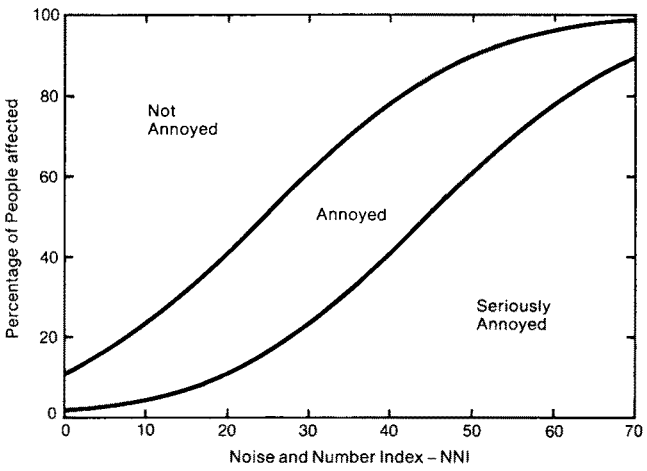
Correlation between noise exposure and individual annoyance is low (typically 0.5). The residual variance, attributable to causes other than noise being considerably greater than that which is apparently due to noise alone. This poor correlation could be attributable to one or more of at least four factors:

(i) incorrect noise scales
(ii) erroneous noise estimates
(iii) inadequate or erroneous annoyance measurements
(iv) inherent differences between people

Undoubtedly all four contribute to some extent but there is now evidence [ref. 2] that factors (iii) and (iv) heavily outweigh factors (i) and (ii). An associated conclusion is that noise scales cannot be refined or improved via survey studies.

Because of the poor correlation it is evident that the use of a noise scale to predict individual annoyance represents a very small improvement over the use of no scale at all. This fact is circumvented in practice by confining attention to average annoyance where the averaging is performed over all people exposed to a very restricted range of noise levels. The correlation between noise exposure and average annoyance is very high (typically in the region of 0.99). A compromise solution is to use a noise formula to estimate average annoyance but to recognize the dispersion of individual annoyance about the mean. Figure 2 is a diagram which is based upon an analysis of a large volume of aircraft noise survey data [ref. 12]. The noise scale in this case is Noise and Number Index [ref. 18] and the curves showing the percentage of exposed people who may be expected to be "annoyed" or "severely annoyed" are probably applicable to residential areas around any major airport at which 20% of aircraft movements take place during the evening or night. Those people who are "severely annoyed" find aircraft noise to be a major influence on their lives and probably the worst feature of local living conditions. The "annoyed" fraction are affected by aircraft noise on occasions and dislike it but would probably not rate it as a major disadvantage. This diagram, which probably typifies the impact of noise nuisance in general, clearly illustrates the magnitude of the differences between people. Because the slope of the curves is so low it is very difficult to select any kind of "acceptability limit" for noise exposure. At any level, large changes of noise exposure result in small changes in the number of affected people.

Figure 2



Complaints give an unreliable guide to the true distribution of anti-noise feeling in the community. Although complainants are highly annoyed people, the fact that a person is highly annoyed does not necessarily mean that he is likely to complain. The reason is that overt reaction is even more sensitive to external sociological factors than is annoyance. These include the individual's education, social status, his ability to express himself and his knowledge of appropriate channels for complaint. Local feelings, publicity and sudden changes in conditions also have a significant effect upon complaint activity. As a consequence there is very little correlation between noise exposure and indices of complaint activity.

Typical activities and consequently noise sensitivity vary with time of day. During the daytime people are working, during the evening they are relaxing or engaged in leisure pursuits and at night they are sleeping. It is therefore logical to divide the day into these three periods and indeed several composite noise exposure scales [refs. 5, 6 and 16] include different sensitivity weightings for the three periods. During the daytime and evening periods disturbance/annoyance mechanisms are rather similar although it has been found [ref. 10] that aircraft noise is roughly twice as likely to disturb during the evening than during the day. At night time sleep disturbance is the important criterion, and it is usually assumed that people are more sensitive to noise at night than during the day. In fact the evidence is that they are not [ref. 10], the likelihood that a night flight will cause disturbance being an order of magnitude less. On the other hand sleep disturbance arouses strong feelings and complaints about this are more likely to receive a sympathetic hearing than those about TV interference for example.

Summary

Severe noise problems involving a small number of people can often be solved following a detailed examination of the factors involved. At very least, provided the necessary resources are available, the noise source and the offended people can usually be separated by distance or by sound insulation. More usually, however, real noise nuisance problems are very complex, involving trade-offs between the benefits of less noise and the costs of lessening it. It is clearly desirable to minimise the harmful effects of noise upon public health but how low must the limits be set and can the costs be met?

In general the environmental planner is faced with two problems, firstly to predict the extent and severity of environmental noise impact and secondly to assess the acceptability, or otherwise, of this impact in some absolute sense. The second of these problems is perhaps the more difficult as its solution ultimately rests on the political question of how many affected people can be justified. But the first is of no less importance since the policy-maker must be able to make qualitative evaluations of the effects of different policy options.

This paper examines the problem of environmental noise nuisance what it is and how it can be measured and predicted. Detailed methodology is beyond the scope of the paper which concentrates instead upon a discussion of the factors involved and the nature of the relationships between them.

Zusammenfassung

Belästigung durch Umgebungslärm

Ernsthafte Lärmprobleme, die eine kleine Gruppe von Personen betreffen, können oft durch eine detaillierte Studie der fraglichen Faktoren gelöst werden. Im allgemeinen können die betroffenen Personen wenigstens durch eine entsprechende Distanz oder Geräuschisolation von der Lärmquelle getrennt werden. Die schädlichen Auswirkungen des Lärms auf die Volksgesundheit müssen auf ein Minimum reduziert werden, aber sind die Kosten tragbar?

Im allgemeinen sieht sich der Umgebungsplaner zwei Problemen gegenüber, erstens das Ausmass des Umgebungslärms vorauszusagen und zweitens sein erträgliches Maximum festzusetzen. Das zweite dieser Probleme ist wahrscheinlich das schwierigere, da seine Lösung auf der politischen Frage beruht, welche Anzahl betroffener Personen gerechtfertigt ist. Aber auch das erste Problem ist sehr wichtig, da qualitative Schätzungen der Wirkungen verschiedener Verfahrensmöglichkeiten gemacht werden müssen.

Dieser Artikel prüft das Problem der Belästigung durch Umgebungslärm, aus was er besteht und wie er gemessen und vorausgesagt werden kann. Der Artikel will keine detaillierte Methodologie aufstellen, sondern sich auf die damit zusammenhängenden Faktoren konzentrieren sowie auf ihre Beziehungen zueinander.

Résumé

Bruit ambiant excessif

De sérieux problèmes de bruit concernant un petit groupe de personnes peuvent souvent être résolus à base d'un examen détaillé des facteurs y relatifs. Au moins, pourvu que les ressources nécessaires soient obtenables, la source du bruit et les personnes affectées par ce bruit peuvent être séparées soit par une distance adéquate soit par des mesures d'isolation sonore. Il est certainement désirable de diminuer les effets nuisibles sur la santé de l'homme, mais où fixer les limites minimum et est-ce que les frais ne surpassent pas les moyens?

En général, deux problèmes doivent être résolus: prédire le volume et la sévérité du bruit ambiant et déterminer son maximum acceptable. Le second de ces problèmes est peut-être le plus difficile, en vue du fait que sa solution dépend de la question politique: quel est le nombre justifiable de personnes affectées? Mais le premier n'est pas moins important, puisque des évaluations qualitatives concernant les effets des différents procédés possibles doivent être faites.

Cet article examine le problème du bruit ambiant excessif, ce qu'il est et comment il peut être mesuré et prédit. Une méthodologie détaillée n'est pas l'intention de cet article, qui veut uniquement se concentrer sur la discussion des facteurs y relatifs et la nature de leur relations.

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