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DAMAGE AND ANNOYANCE CAUSED BY NOISE

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Prepared by

Prof. H. Bastenier,
Prof. W. Klosterkoetter
Prof. J. B. Large

Directorate-General for Social Affairs
Health Protection Directorate

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PREFACE

Note from the Secretariat

At the first meeting of national experts on noise organized within the framework of the Commission of the European Communities at Luxembourg 28 to 30 November 1973 a small group of rapporteurs were requested to prepare a joint report on the most significant effects of noise on man.

The rapporteurs:

Prof. H. BASTENIER
Prof. W. KLOSTERKOETTER
Prof. J.B. LARGE

met at Brussels and agreed to consider the following aspects of the action of noise:

1. damages of the auditory apparatus
2. cerebral activation reaction
3. noise interference with speech and acoustic orientation
4. noise interference with performance
5. population annoyance problems
6. conclusions and recommendations

Points 2 and 4 were prepared by Prof. Klosterkötter, 3 and 5 by Prof. Large and 1 and 6 by Prof. Bastenier.

This report is the scientific background and support for document number V/F/2949/74, "Elements for inclusion in a document on criteria and guide-levels for noise" prepared by the Secretariat.

Directorate-General for Social Affairs

Health Protection Directorate

Luxembourg

FOREWORD

Noise is an environmental nuisance, complex in its effects and their interpretation; "criteria", following the definition proposed by WHO, and annoyance indices are now being determined within the Commission of the European Communities.

The present report is a remarkable work summarizing and reflecting on the latest available scientific data, which as described and analysed could lead to the establishment of a quantitative relation between "noise exposure" and an undesirable or an unacceptable effect, from the standpoint of human health. In this report one finds a sufficient basis and a useful guide for the elaboration of criteria and norms for the European Community.

The authors of this report are to be warmly congratulated for having prepared for the Commission a scientific contribution of such great value that another stride has been taken towards fulfilment of the Action Programme on the Environment: it is now possible to consider setting levels to reduce, in a reasonable and realistic way, the extent of a nuisance which has a certain, but to some degree variable, effect on the health and comfort of the population.

Dr. P. RECHT
Director
Health Protection

1. INTRODUCTION

The first meeting of national experts on noise held within the framework of the Commission of the European Communities in Luxembourg from 28 to 30 November 1973 reviewed all the known effects of noise on man. For the Public Authorities to envisage recommendations for the protection of the population it is not sufficient for the effect of noise on the organism to be observed or even the obvious damage that the effect can cause: one needs to establish a relationship between the importance of the noise and the damaging effects considered. It is necessary to establish threshold levels for which the considered effects will occur. The effects of noise on the body which exist have been observed and reproduced experimentally in animals but without being able to say that this effect necessitates a similar alteration to health. With noise effect on the electric resistance of the skin (skin resistance level - SRL, skin resistance response - SRR) Klosterkötter has shown that with noises of between 30 and 80 dBA increases of more than 3 to 6 dBA are sufficient to significantly change the SRR.

With an increasing base level the reaction of the vegetative nervous system increases in a disproportional way between 50 and 60 dBA. On repeating the annoyance the SRR shows rapid acclimatization. This signifies that within the bounds of our present knowledge it is impossible to utilize information concerning the threshold of irritation and the amplitude of the SRR reactions to determine the threshold levels as well as the dose-effect relation of noise.

This is the same for all actions of noise such as activation of the endocrine system, the reaction of pupil dilation, the effect on the respiratory system and the spinal arousal reaction producing an increase in the spontaneous electrical activity of the muscles and muscular tension.

Many studies have been made of the effects of noise on the cardiovascular system: these have confirmed the existence of a vasoconstriction reaction at the level of the pulse or on the arteries at the base of the eye. It seems that this reaction (VCR - vasoconstrictory reaction) has an appearance threshold of 50 dBA but when one analyses the results critically it appears that they all exist within the normal adaptation of the cardiovascular system to the circumstances of normal life. It has not been proved that they constitute a menace to the health of the population to the point which justifies intervention by the Public Authorities. It was, therefore, necessary to make the choice: certain effects of noise have been discarded because proof of damage to public health is inadequate, other effects are discarded where a dose-effect relationship is too imprecise to define a guide-level. New research is necessary but although recommendations may be indispensable they are premature at this moment.

On the other hand certain effects of noise on the organism have been studied sufficiently to warrant action by the Public Authorities: these effects are listed in the conclusions.

2. DAMAGE TO THE AUDITORY MECHANISM CAUSED BY ACOUSTICAL NUISANCES

Experience of acoustical nuisances in industry allows two types of damage to the auditory mechanism to be distinguished:

- damage from acute noise effects
- damage from chronic noise effects.

2.1. Acute noise effects

2.1.1. Rupture of the ear-drum

When a shock wave is created in the air following an explosion, the air molecules are compressed suddenly, within a time of the order of 1×10^{-5} seconds or even less.

At the source, the resulting compression is of the order of hundreds or even thousands of psi.§ Near to the source the molecules are propelled for some distance before starting to oscillate, and once oscillation has begun a shock wave is created and expands radially, during the propagation of which its speed and the excess pressure peak rise at a rate higher than the inverse ratio of the square of the distance (19). The shock wave may thus be defined as a sound wave having a high initial compression and a high speed. It follows that the ear, as an organ specially designed to receive a sound wave, will receive the excess pressure of an explosion in the same way.

Being extremely sensitive, the ear responds to energy levels as low as 10^{-6} W per square centimetre, or 2×10^{-10} atmospheres. Even such low forces are capable of causing the ear-drum to move(45).

The ear-drum cannot, however, respond faithfully to pulses with a period below 0.3 ms, but it attempts to do so by executing a single high-amplitude movement, which results in rupture.

When a shock wave is produced in air at a given distance from the ear, the pressure at the ear-drum is 20 % higher than the pressure which would be recorded in the open air the same distance away.

§ psi = pounds per square inch

A concentration effect obtains, due to the shape of the external auditory canal (45). When an explosion occurs, the pressure on the ear-drum varies with the distance, the position of the subject relative to the source, the type of explosion and the surroundings. There is a direct relationship between the percentage of ear-drum ruptures and the maximum excess pressure (110). For a given pressure peak, the percentage of ear-drum ruptures rises proportionately with the rise in the rate at which the pressure increases.

The wave of excess pressure produced by an explosion comprises two phases, a fast, intense, positive phase and a slower, less intense, negative phase. It is equally possible for ear-drum rupture to occur during the negative phase, particularly when it is significant and prolonged (19, 45, 50, 110).

The vulnerability of the ear-drum varies with age, a phenomenon which is attributable to greater ear-drum elasticity in young people. Older people possess fewer elastic fibres and these are less regularly organised in the submucosal tissue (45).

In an explosion, an excess pressure of 15 psi or about 1 atmosphere, rising rapidly, will cause ear-drum rupture in 50 % of the people exposed. An excess pressure of more than 2 atmospheres, propagated with the speed of a shock wave, will cause ear-drum rupture in all the people exposed (106).

Since ear-drum rupture is caused by the blast of the explosion and not by the accompanying noise, the question arises whether very intensive noises, unaccompanied by blast, are capable of rupturing an ear-drum on their own.

It is reported that a volunteer who exposed himself to an 8500 Hz noise with a progressively rising sound pressure level suffered rupture of the ear-drum when the sound pressure rose from 156 dB to 164 dB (22). Noise on its own, therefore, is capable of causing rupture of the membrane of the ear-drum. It must be noted that ear-drum rupture resulting from an acoustic trauma never damages Shrapnell's membrane. Expert opinion takes the view that rupture of this membrane is adequate for the hypothesis of an acoustic trauma resulting from an explosion to be disregarded (16).

Ear-drum rupture resulting from an acoustic trauma immediately causes mixed deafness (36, 45, 94, 110), consisting simultaneously of transmission deafness which will disappear with the spontaneous healing of the ear-drum and reception deafness resulting from damage to Corti's organ, from which varying degrees of temporary or permanent deafness may remain. This damage is attributed to excessive mobilization of the endolymph.

Loss of hearing is observed as much with low-pitched as with high-pitched sounds

- it is of the order of 10 to 30 dB in the low frequencies but may reach 40 to 80 dB for the high frequencies.

Cases have been described of ear-drum rupture with dislocation of the chain of auditory ossicles and even propulsion of the stirrup bone into the oval window (94). Such a phenomenon is unusual and occurs only in the event of considerable excess pressure. The result is severe and permanent transmission deafness.

It is not possible to establish a correlation between the size of the perforation of the ear-drum and the degree of immediate hearing loss.

2.1.2. Sudden deafness without rupture of the ear-drum

Certain German authorities (3, 7, 60).have reported the occurrence of deafness which appeared suddenly and on one side only in workers employed in noisy surroundings, in every case with a level higher than 90 phon. These observations have been confirmed by French authorities (35, 97) and a Japanese authority (59) has carried out an analysis of known cases.

The auditory trouble in these cases is pure perception deafness, most frequently on one side although cases have been reported of bilateral damage (3, 59, 97). The audiogram takes the form of a flat plot with a maximum drop around 1000 Hz, although sometimes it is U-shaped, rising at frequencies higher than about 4000 Hz.

Hearing loss is accompanied by tinnitus and recruitment. Vertigo does not occur, the examinations of the vestibules are negative, and the ear-drum is intact.

This sudden deafness is irreversible.

The theory of circulatory trouble in the cochlea has been advanced based on the U-shaped or flat trace of the audiogram, on the constant presence of recruitment and on the results of vasodilatory therapy.

Certain authorities (3, 7) attach particular importance to an abnormal position of the cervical column at the moment when the sudden deafness occurs, this position being such that an interruption of the circulation in the cochlea artery is likely (59).

2.2. Effects of long-term exposure to high noise levels

2.2.1. Auditory fatigue

When workers who are exposed all day long to a noise with a sound pressure exceeding 90 dB stop work, tonal audiometry commonly indicates that their objective audibility threshold rises. This shift is temporary and the subject subsequently regains his normal hearing.

If this temporary rise in the threshold persists for more than 2 minutes after work has stopped, the phenomenon is known as temporary threshold shift (TTS_2).

On the audiogram the hearing loss is often most significant at a frequency of 4096 Hz (111), but the maximum may be situated anywhere between 4000 and 6000 Hz (38).

In general the temporary hearing loss is most marked at half an octave or 1 octave above the highest frequency of the noise.

The temporary threshold shift is proportional to the logarithm of the exposure time (127). If the noise is interrupted, the temporary threshold shift is less, unless the interruption results in a succession of very brief noises reaching their maximum sound pressure level in a very short time (67, 118).

Temporary threshold shift is proportional to the difference between the acoustic pressure of the noise under consideration and the critical value of 85 dB (127).

Temporary threshold shift does not generally arise where the sound pressure is lower than 85 dB. Individual variations do occur, however, and a case of temporary threshold shift lasting more than 2 minutes after work stopped has been observed with a sound pressure of 78 dB. This is totally exceptional.

Regular exposure to noises with an intensity insufficient to provoke temporary threshold shift can have a cumulative effect and may increase hearing loss if exposure should later occur to noise with an intensity over 85 dB.

Sounds consisting of pure tones appear to have a greater influence on temporary threshold shift than sounds distributed over a wide band of frequencies. The frequencies from 300 to 600 Hz appear to be less harmful than those between 2000 and 4000 Hz.

The hearing loss measured 2 minutes after work in noisy conditions fades away during the subsequent hours and hearing recovers exponentially. Recovery occurs more slowly if it takes place in noisy surroundings. If the temporary hearing loss, measured 2 minutes after work stops, is more than 50 dB, recovery may be much slower and may take more than a day (21, 127).

This has given rise to the idea that a temporary threshold shift of 50 dB at 4000 Hz ought to be considered as the acceptable limit.

The temporary threshold shift measured 2 minutes after work stops may be useful for prognostic purposes (88). It is considered that continuous exposure for 8 hours to a noise causing a given temporary threshold shift will, in 10 years of exposure, cause a permanent hearing loss equal to this temporary threshold shift (88, 105).

2.2.2. Permanent hearing loss

Daily exposure to very intense noises, reproduced regularly, can lead to irreversible hearing loss. This occurs insidiously in people whose temporary loss after 2 minutes is more than 50 dB at the frequency of 4000 Hz. The period during which a permanent hearing loss becomes settled does not appear to be more than 1 month. The damage is bilateral, and is at its maximum for the frequency bands between 3000 and 6000 Hz (4, 37, 38, 50, 83).

Once established, this permanent loss increases very little during a totally latent period, which may last several years. If the exposure to noise continues, the audiogram changes again during a period of sub-total latency which may last from 2 to 15 years, whether the deterioration is progressive or occurs in a series of jerks.

The deterioration in hearing becomes evident by a reduction at the frequency most affected and by a spreading of the loss towards the low frequencies, over a band of 2 to 3 octaves from the maximum loss. Again, the permanent loss remains stable, sometimes for 30 years.

Finally outright deafness occurs, in which the permanent loss reaches levels higher than 85 dB extending down to the low frequencies of 1000 or even 500 Hz.

Various factors can influence the progression towards outright deafness.

It is certain that for a given exposure time and a given frequency, the higher the sound pressure, the greater the permanent hearing loss (66, 83, 88). Similarly, the longer the exposure lasts, the greater will be the loss of hearing, all other factors being equal.

The frequency of the noise also has an effect, the octave bands above 2000 Hz being more harmful. Several authorities (67, 69, 115) have drafted curves of equal fatigue effects for different octave bands.

As in the case of temporary threshold shift after 2 minutes, final hearing loss is influenced by whether the noise is continuous or interrupted. An interrupted noise appears less harmful than a continuous noise of the same intensity and at the same frequency (30, 66, 101).

On the other hand a series of interrupted noises occurring at a rapid rate, as in the regular use of fire-arms or the operation of compressed-air hammers, appears to be more harmful than a continuous noise of the same intensity.

Pulsed noises occurring at a rate of between 6 and 60 pulses a minute appear to be more harmful than the same pulsed noises occurring at a rate of 2 a minute.

Two factors having an important effect on the harmfulness of pulsed noises are the maximum sound pressure and the time taken to reach it. In the case of interrupted noises, the overall average sound level multiplied by the time during which this level is maintained gives the level of harmfulness corresponding to the effect of a continuous noise.

There are differences in individual susceptibility to permanent hearing damage. This variation follows a statistical curve, as in the case of temporary threshold shift, but differs from the latter in having a far wider distribution (41). To date, an absolutely certain test of susceptibility to permanent hearing loss has not yet been discovered.

Convincing confirmation of predictions based on observation of temporary threshold shift in the early exposure period would require a study of a sufficient number of subjects exposed to known and unvarying noises for about 10 years. The realities of industrial activity make the valid performance of such a study extremely difficult.

The various factors influencing the appearance and development of a permanent loss of hearing make it difficult to establish a risk criterion, i.e. a level of noise below which no reductions occur in the auditory acuity of subjects habitually exposed to it and having normal ears.

In the case of exposure to continuous noises, ISO proposes that the tolerable threshold should be determined by means of the NR 85 evaluation curve. Observation of this standard does not cause hearing loss of more than 12 dB in the conversational frequencies after an exposure of 5 hours per day for 5 days per week.

Other criteria are based on the observation of temporary threshold shift measured 2 minutes after exposure stops (TTS_2). A number 1 curve is given as an acceptable standard for continuous exposure 8 hours a day. It is very close to the NR 85 evaluation index (ISO standard), and guarantees that the temporary threshold shift will not exceed 10 dB at 1000 Hz, 15 dB at 2000 Hz and 20 dB at 3000 Hz. Other curves for equal risks, i.e. giving the same temporary threshold shift, have been drawn up for exposure times of less than 8 hours (CHABA standards).

The exposure limits proposed by the American Conference of Government Industrial Hygienists guaranteed that at the end of working life the average hearing loss would be 15 dB at 500 Hz, 1000 Hz and 2000 Hz. These standards provided for a limit of:

85 dB for 4 to 8 hours exposure
90 dB for 2 to 4 hours exposure
95 dB for 1 to 2 hours exposure
100 dB for less than 1 hour exposure.

To allow for the greater harmfulness of sounds consisting of pure tone components, the standard can be lowered by 5 dB in the case of noises of a very narrow frequency spectrum. In order to deal with the complications resulting from exposure for different lengths of time to differing noise levels, it has been proposed that a level equivalent to continuous noise should be calculated, based on a partial exposure index taking into account the exposure time and the noise level corresponding to the average of the corresponding sequence.

ISO recommendation R 1999 indicates the calculation of an equivalent noise level. The equivalent level is expressed in dB(A). The recommendation presages that the risk criteria is situated at a noise equivalent level of 90 dBA.

3. AROUSAL OF THE CENTRAL AND AUTONOMOUS NERVOUS SYSTEMS BY AUDITORY STIMULATION

3.1. Mechanism of the activation reaction

Auditory stimulation causes arousal of the central and autonomous nervous systems (cortical, spinal, affective and autonomous arousal reactions). Arousal is transmitted by the interaction of cortical, thalamo-reticular, sympathetic and neurocrine structures and functional cycles. Arousal reactions can partly be recognised by behavioural reactions, partly be experienced subjectively and for the most part be objectively determined and recorded by physiological and biochemical methods (electroencephalography, electromyography, skin resistance response, plethysmography, measurement of blood pressure and pulse rate; measurement of skin temperature, pupillometry, measurement of respiratory rate; determination of catecholamines and corticoids). Few of these reactive systems have hitherto been investigated systematically and in relation to acoustic stimulation thresholds and the application of the results to real-life situations.

Arousal reactions are physiological indicators of the way in which the body copes with auditory stimuli. They are not produced solely by noise, neither are they pathological as such; but under certain conditions they are undesirable and possibly pathogenic.

3.2. Cortex Activation

3.2.1. Auditory stimuli and sleep disturbance

With regard to the effects of noise, the most important negative consequence of arousal is the adverse effect on sleep patterns. Sleep disturbance takes the following forms:

- falling asleep becomes more difficult and takes longer;
- qualitative and quantitative effects on the cyclic sleep pattern without awakening;
- awakening.

To fall asleep, the organism's psychophysical arousal level must fall. This cannot happen unless the influx of stimuli (exteroceptive and proprioceptive) is reduced. This also relates particularly to the ambient acoustic conditions. According to a Russian study (quoted in (125)), the process of falling asleep was extended to 1½ hours with a noise level of 50 dB as against 20 minutes with 35 dB. One can, however - as practical experience (ships' and railway sleeping cars, personnel,etc)and sleep experiments (56) show - fall asleep at considerably higher homogeneous continuous noise levels (60 to 70 dB), at which, according to JANSEN (56), it often takes longer to fall asleep.

Empirically it is known that noise-induced difficulty in falling asleep can be very disagreeable; it can be accompanied by affective arousal and vegetative sensations and often causes people to resort to sleeping pills. Everyday experience seems to show that, individuals can acquire different levels of tolerance, although we have no definite knowledge to what extent. Violent fluctuations in noise level and noises with meaningful associations create conditions that make falling asleep difficult. Theoretically and empirically it seems that the stage of falling asleep is more susceptible to noise than sleep itself, although there are no quantitative findings on this point.

Sleep typically progresses in a cycle of changing stages (I - IV, REM)* (23, 128). According to WEBB and AGNEW, longer stages of deep sleep (III, IV) only occur in the first three hours of sleep, whereas in the last three hours longer stages of REM predominate. In the normal human-ageing process sleep becomes lighter and increasingly fragmented (133); at the age of 45 sleep stage IV occurs less frequently and is almost totally absent from 60 onwards. According to WILLIAMS and WILLIAMS (135), normal young men in whom stage IV did not occur were particularly susceptible when deprived of small amounts of sleep.

* REM : Rapid eye movements

Investigations into the effects of noise on sleep have shown that sleep stages are changed and periods of deep sleep and dreaming sleep (stage IV and REM) are shortened without the test subjects waking up (91, 98, 122, 123, 133, 134, 135, 140). Experiments involving sleep loss have shown that, the following night, loss of deep sleep is offset by an extension of stage IV and loss of dreaming sleep is then offset by an extension of the REM stage. This suggests that these sleep stages are biologically significant.

Sound stimuli during sleep can cause autonomous reactions that belong, according to DAVIS et al. (20), to the range of N-responses (25, 55, 56, 91, 100, 124, 134). JANSEN (55) established a vasoconstrictive reaction (VCR) of the cutaneous vessels in the fingertips at 55 dB; according to OTTO (91), the stimulation threshold for changes in the heart interval is 45 dB and for respiratory reaction 50 dB; ROSENAU (100) found in infants an average stimulation threshold for respiratory reaction of 53 to 60 dB; according to DÖRING et al. (25), the VCR threshold in sleeping babies was about 70 dB. WILLIAMS et al. (134) were able to prove that the sleep stage at a given moment does not affect the VCR threshold, in contrast to EEG and behavioural reactions. According to BROUGHTON et al. (12), the stimulation threshold for electrodermal reactions is considerably lower in stages II - IV than in the REM stage and when awake, which they attribute to the decrease in cortico-reticular inhibitory processes during sleep. This may also be the explanation for the lower VCR threshold during sleep, which was observed by JANSEN (55) (55 dB as against 65 to 70 dB when awake).

The strongest reaction to noise stimuli is awakening. The awakening reaction displays quantitative differences ranging from ordinary awakening, followed by rapid return to sleep, to startled reaction. The latter results in a wide-awake state, often linked with sensations due to the neurovegetative system, and in a considerable delay in going back to sleep.

As the investigations of numerous authors (40, 90, 96, 122, 134) have shown, acoustic awakening thresholds are dependent on a number of variables: noise intensity, EEG sleep stage, inter- and intra-individual variables, accumulated sleeping time, amount of previous sleep loss, time of night, previous subjective experience of the sound stimuli, conditioning and motivation, and the meaningful content of the sounds. According to KRYTER (68) the awakening probability increases with the noise intensity, with basic EEG frequency (except in the wake-resistant REM stage), with the progression of the night and with the amount of sleep accumulated. The more sleep a person needs, the higher are the acoustic awakening thresholds. Some authors reported that test subjects had the capacity to acquire a certain tolerance of noise (decrease in awakening frequency) (56, 75, 122, 123, 133); this did not, however, apply to sonic booms. Everyday experience proves that the extent to which we can become accustomed to familiar noises, thereby safeguarding our sleep, is considerable.

3.2.2. Influence of lack of sleep on Community health

There are no definite data on the relation between health and noise-induced disturbance of sleep-patterns. As for the qualitative changes (changes in the EEG pattern during sleep, shortening of deep-sleep period stage IV and of dreaming sleep period REM without awakening), it should be pointed out that frequent disturbance of the biologically programmed cyclic sleep pattern may have a deleterious effect on the regenerating capacity of sleep and on the health of those concerned.

The fact that EEG stage IV and the REM stage are made-up after sleep loss (134) indicates that these are biological necessities. However, definable effects on health by qualitative sleep pattern disturbances are not as yet known.

Interference with the process of falling asleep (difficulty, prolongation) and noise-induced awakening are on the one hand intensely annoying and on the other hand can lead - varying from person to person - to loss of sleep. What suffers most on the day after noise-induced sleep loss is the capacity to perform work requiring good short-term memory and the ability to process information quickly (WILLIAMS (133)). A person's psychophysical state can be considerably impaired on the day after sleep has been lost; increased elimination of catecholamines can also occur. According to FOULKES (31), there is no doubt that even brief loss of sleep threatens a person's ability to adapt to his surroundings. Although the reason for and significance of sleep have not yet been fully explained, nobody disputes that it is biologically necessary; however, it is not known what indirect or direct consequences result from frequent sleep losses. Qualitative and quantitative noise-induced disturbances of the sleep pattern can probably be offset to a certain extent by internal and external regulatory functions. But under the sociocultural conditions of our society it is probable that there is often not sufficient scope for offsetting noise-induced sleep loss.

3.2.3. Threshold value of noise necessary to affect sleep with justification of the values

Various points must be borne in mind when establishing guide-levels for environmental noise which are intended to guarantee tolerable sleeping conditions.

It seems expedient to propose guides for internal noise levels in bedrooms. When external noise levels are known, they can be converted according to ISO R 1966 - 1971 (E) as follows: with bedroom windows open - 10 dB (A), with single-glazed windows shut -20 dB (A).

Of the very many publications dealing with the effect of noise on sleep, only few contain concrete indications of awakening thresholds and stimulation thresholds for variations in the electrobiological sleep pattern. Useful data can be found in the following studies: THIESSEN (122) found in experiments using lorry noise of 40 - 70 dB (A) that, in more than 10 % of cases, 40 - 45 dB (A) induced shallower sleep or awakening; at 50 dB (A) shallower sleep or awakening were noted in 50 %; at 70 dB (A) awakening was the most frequent reaction. The probability of no reaction occurring at 70 dB (A) is slight.

LUKAS and KRYTER (75) experimented with simulated sonic booms and sub-sonic aircraft noise. They found that the tendency to wake up varied unmistakably according to age. At intensities of 1.25 psi, seven to eight-year-old test subjects were woken up by 0.9 % of the booms, 41 to 45-year-olds by 2.4. % and 62 to 72-year-olds by 68.2 %. With overhead aircraft noises of 107 PNdB (approx. 95 dB (A)) the respective percentages for the above age-groups were 0.9 %, 10.5 % and 72.2 %.

VOGEL (126) and GÄDKE et al. (34) carried out tests on 126 babies. They found that the threshold for sleep pattern disturbance or awakening was 50 dB (A); at 75 dB two-thirds of the babies had their sleep qualitatively changed or interrupted. This applied to a 3-minute noise of 100 to 7000 Hz; if the 75 dB noise lasted 12 minutes, qualitative sleep changes or awakening occurred in 100 % of the subjects.

ZIMMERMANN (139), who had investigated in an earlier study (138) psychological and physiological differences between "light" and "deep" sleepers ("light" sleepers are said here to be of a more nervous disposition), tested the auditory awakening thresholds in subjects of these two types. In the case of light sleepers, the awakening threshold in EEG sleep stage IV was 78.4 dB, in II 60.3 dB, in REM stage 56.6 dB, in III 57.8 dB, in II 55.7 dB, in REM 55.0 dB, in II 51.1 dB; in the case of deep sleepers, the following values were determined: in stage IV 85.0 dB, in II 75.9 dB, in REM 70.9 dB, in III 74.7 dB, in II 70.3 dB, in REM 72.3 dB, and in II 66.2 dB.

OTTO (91) found that with 60 phon stimuli the deep sleep period was significantly longer and the short waking periods were considerably shorter when the test subjects wore earplugs. According to JANSEN (56), test subjects can fall asleep and remain asleep all night with a continuous noise level of 70 dB (A), but then their total period of deep sleep is shorter. Single noises of 50 to 55 dB caused deep sleep to become shallow and shallow sleep to be interrupted by awakening.

SPRENG (116) recently showed that a 10 dB change in the normal environmental level of familiar sounds raises the arousal level of the central nervous system sufficiently to cause people generally to wake up.

The studies by BRUCKMAYER and LANG (13) are also of interest.

Effect of nocturnal noise in a bedroom as a percentage of people affected

Noise level dB(A)	Windows open			Windows closed		
	Undisturbed	Disturbed	Very disturbed	Undisturbed	Disturbed	Very disturbed
25 - 30				50	26	24
30 - 35	74	26	0	31	27	42
35 - 40	54	10	36	17	31	52
40 - 45	35	9	56			
45 - 50	18	12	70			

This experiment shows that the effect of sleep depends not only on the noise levels but also on the magnitude of the fluctuation with respect to the background noise.

AUBREE, AUZOU and RAPIN (2), however, found that sleep disturbance is relatively common among the population as a whole and that there is no correlation between this disturbance and the external noise levels recorded. It is true that from an external noise level of 60 dB (A) (L_{50}) upwards sufferers from frequent sleep disturbance attributed it to noise far more often than was the case at 57 dB (A).

If we look at these results as a whole, we see on the one hand that the threshold range for objectively demonstrable effects on sleep patterns is from 40 to 50 dB (A) (maximum noise level) and that the arousal threshold of the central nervous system corresponds to a level approx. 10 dB (A) higher than the normal environmental level. It can be deduced from this that the nocturnal average noise level (noise equivalent level) in bedrooms should be between 30 and at the most 35 dB (A), and the average maximum noise level

(L_1) should not exceed the noise equivalent level by more than 10 dB (A). Here a certain safety margin has been taken into account for the more susceptible elderly people.

3.3. Noise and interference with relaxation

Man's daily life contains states of tension and relaxation which, to a large extent, alternate autonomously. This phenomenon is associated partly with circadian rhythms and partly with activities which precede the tense or relaxed state.

Everyday experience shows that - as when falling asleep and during sleep - noise can prevent the onset of relaxation and interrupt the relaxation phase itself and turn it into one of tension. One is more susceptible to disturbance when one is beginning to relax than when relaxation is well established. Although as yet no systematic studies have been carried out on threshold ranges, there are indications that unexpected and/or violently fluctuating noises are of greater significance than the average noise level; However, when investigating skin resistance response at various basic noise levels, Klosterkötter (64), observed a highly disproportionate increase in the response between 50 and 60 dB (A). This led him to conclude that the basic noise level should be taken into account when arousal reaction is considered. As there are no concrete data available for establishing environmental guide-levels for noise conducive to relaxation, it would appear expedient to set these between the values for sleeping (night-time) and for the waking hours (daytime), at the same time bearing in mind, when considering average maximum noise level, (L_1), the central nervous arousal threshold of 10 dB observed by Spreng (116).

The problem of interference with relaxation is one which particularly affects the sick and those who are convalescing or are in need of recuperation. It is biologically necessary to safeguard such people's relaxation and to remove from them all noise stimuli which produce an arousal reaction. This is borne out by medical experience, although as yet this point has rarely been the subject of specific examination;

For exemple, Klosterkötter (63) was able to show, by measuring skin resistance, that a significantly greater autonomous response to noise stimuli occurs among hypertensive persons than among those with normal blood pressure.

Consequently the persons referred to above, each category of whom represents a fairly considerable percentage of the population, require special protection from noise, particularly in hospitals and convalescent establishments. In such places average noise equivalent levels (L_{eq}) and noise fluctuation should be as low as possible, both outside the buildings and indoors when windows are open. The following would appear to be acceptable guide-levels for these places: average external noise level (L_{eq}) during daytime 45 dB (A), and at night 35 to 40 dB (A); average internal noise level during daytime 35 dB (A), at night 25 to 30 dB (A); the average maximum noise level (L_1) should if possible not exceed the above internal levels by more than 10 dB (A). This would seem to provide an adequate safeguard for night-time and daytime sleep, relaxation, and also for the use for relaxation of open-air facilities such as balconies, terraces and gardens.

3.4. Spinal arousal reaction (muscular state and EMG)

Noise stimuli cause spontaneous myoelectric activity and muscular tension to increase. This fact may be demonstrated electromyographically (EMG), and numerous works refer to this, including those of Davis et al. (20), von Eiff (27, 28) and Hörmann (47). There are no concrete data available concerning the EMG response under practical acoustic conditions. This response, although very interesting from an experimental point of view, has not yet provided any information which could be used to establish guide-levels.

3.5. Autonomous arousal reaction

It has long been known that all stimuli - apart from those which may have particular sensory and cortical effects - produce responses in peripheral and/or visceral systems (Davis et al. (100)). With regard to the problem of noise it is important to determine whether noise affects health directly or indirectly, and whether stimulation thresholds and response levels can be used to establish environmental guide-levels.

Numerous papers have been written concerning cardiovascular responses, responses of the respiratory system, the pupils, skin resistance and the hormonal system. Most writers have worked on short and pronounced noise stimuli, and tests with a practical emphasis are rare. Some writers tend to generalise on the basis of results of laboratory experiments which have no bearing on real-life conditions, and to draw sweeping conclusions from these.

3.5.1. Cardiovascular responses

According to LEHMANN and TAMM (73), noises of 70 to 90 phons cause a decrease in pulse volume, an increase in peripheral circulation resistance together with restricted pressure amplitude and a certain amount of bradycardia. They describe the behaviour of the circulatory system as very disturbing. ETHOLM and EGENBERG (29) tested these results using the recently developed and reliable heart catheter method. They obtained no significantly irregular findings at 90 dB with O_2-intake, O_2-arteriovenous difference, pulse volume, cardiac output, heart rate and blood pressure in the arteria pulmonalis. The findings of LEHMANN and TAMM and the sweeping conclusions they derived from them can thus be considered to be refuted.

HEINECKER et al. (44) conducted a thorough investigation into the response of blood pressure and other circulatory functions to noises of 90 dB. They referred to "considerable circulatory response". However, critical analysis of their findings reveals that all the responses lie within the normal adaptability range for the cardiovascular system under everyday conditions. KLOSTERKÖTTER carried out tests on a large number of subjects under various test conditions and found that the response of blood pressure to noise stimuli was negligible.

Vascular response in the fingertips has been the subject of very systematic and thorough examination (55, 62, 64, 72). This may occur as a vasoconstrictive response (VCR) or, more rarely, as a vasodilatatory response (VDR). VCR is symptomatic of a change in blood distribution and not of a circulatory disturbance: it is not indicative of vasoconstriction in other vascular regions. For example, in case of VCR of the skin muscular circulation increases (39).

JANSEN (55) found that third-band and wide-band noise produced a VCR stimulation threshold of 60 to 65 dB; from 75 dB the VCR readings were statistically significant.

KLOSTERKÖTTER (64) found that traffic noises produced a VCR stimulation threshold of 50 dB (A) and a statistically significant reaction from 60 dB (A).

KNÖPKE (65) showed that VCR is more pronounced when performing mental calculation lasting one minute than when people are subjected to a wide-band noise of 105 dB. JANSEN (55), on the other hand, is of the opinion that because of noise-induced VCR the tolerance limit of wide-band noises ought to be set at exactly 88 dB.

If a critical assessment of the overall VCR test results obtained to date is made, the conclusion must be that neither the experimentally determined stimulation thresholds nor the degrees of response dependent on noise intensity can be used to establish environmental guide-levels. There is furthermore no indication that VCR, which falls within the category of N-responses,(20) has any pathogenetic significance. A study (54) was conducted under this assumption and does not - as far as determining the relevant symptoms, obtaining findings, describing the "collective" and factors relating to places of work and processing statistics are concerned - meet the requirements which are a pre-condition for epidemiological and statistical investigations of this type.

3.5.2. Responses of the respiratory system

DAVIS et al. (20) are among those who have written on the subject of respiratory rate and amplitude. The available documentation does not bring to light any practical information which could be used to establish guide-levels.

3.5.3. Response of the pupils

The dilatory response of the pupils to noise stimuli has been the subject of a detailed paper by JANSEN (55). The stimulation threshold in laboratory conditions appears to be approximately 75 dB.

The response is seen as an indication of a noise-induced increase in sympathicotonia. There is no information available on the nature of the response in real-life conditions.

3.5.4. Skin resistance response

There is a vast amount of documentation available on skin resistance to noise stimuli (skin resistance level = SRL, skin resistance response = SRR), some of the findings of which contradict each other. This is due to the different methods and approaches adopted. KLOSTERKÖTTER (64), in an attempt to test the usefulness of this pattern of responses under practical conditions, found that the stimulation threshold was very low: with basic noise levels of 30 to 80dB (A) stimuli of plus 3 to 6 dB (A) were sufficient to produce significantly high SRR. With increased basic noise levels the response of this autonomously controlled system rose, and was disproportionate between 50 and 60 dB (A). When the stimuli are repeated the SRR very soon shows signs of tolerance. According to DAVIS et al. (20), SRR is part of the complex of N-responses, while SOKOLOV (113, 114) and LYNN (77) consider it to be part of the complex of orientation reflexes.

Present knowledge does not not permit information on the stimulation threshold and response amplitude of the SRR to be used to propose guide-levels. Further work ought to be carried out to ascertain whether in fact skin resistance response rises when basic noise levels increase, as this may provide an interesting means of assessing noise levels.

3.6. Arousal of the endocrine system

Arousal of the endocrine system may be suggested by an increase in catecholamine secretion (adrenalin, noradrenalin) in the urine and an increase in plasma corticosteroids (1, 32, 42, 74). There are indications that intense noise stimuli may produce responses of this kind; arousal of the endocrine system is probably connected with psychic-emotional stress (intense annoyance, anger, and aggressive tension). It may be that catecholamines also play a part in orientation reflexes and defensive responses (SOKOLOV (113, 114) and LYNN (77)). So far, however, no systematic tests have been carried out on humans to determine the conditions under which noise-induced endocrine arousal reaction occurs. This area, therefore, has provided no useful data for the establishment of guide-levels. The results of tests on animals subjected to generally loud noise stimuli can not be applied to humans (c.f. works of NITSCHKOFF and KRIWITZKAJA (87)).

3.7. Startled reaction, defensive response

Unexpected and/or loud noise stimuli lead to general orientation reflexes with an extended fade-out period or to defensive responses (77, 113, 114) or startle reaction (70, 119). SOKOLOV speaks of defensive response when vasoconstriction (VCR) occurs in the blood vessels of the limbs and head. According to KRYTER (68), startle-type reactions occur as a result of noises which intensify abruptly (40 dB and over in 0.5sec.). Sonic booms of aircraft are typical of this type of noise.

A defensive response as understood by SOKOLOV can also arise when a minor stimulus which first leads to an orientation reflex is repeated frequently. It is rarely possible to accustom to defensive responses and startled reactions: they can even lead to increased sensitivity and a lowering of the stimulation threshold, especially in cases of artificial stimuli.

Defensive responses and startled reactions are indicative of intense arousal of the central and autonomous nervous system. It may be assumed that frequent stress of this kind can lead to distress or strain and should be eliminated wherever possible from the environment. References to limiting values have been made by KRYTER (68) (intensification of 40 dB and over in 0.5. sec.) and SOKOLOV (cited in 77) (defensive response in cases of non-artificial stimuli from 85 to 90 dB). However, these values are not absolute, and the stimulation threshold can fall as a result of frequent repetition of the stimuli.

3.8. Conclusions

When the available knowledge of the arousal of the central and autonomous nervous system by noise (cortical, affective, autonomous and endocrine arousal reaction) is analysed - of which only brief mention could be made here - it is found that this can only partly be used for establishing guide-levels. This is true, for example, in the case of falling asleep, sleep and relaxation, and also to a limited extent in the case of defensive responses and startled reactions. According to information acquired to date, which is largely the result of laboratory experiments, standard values for normal environmental conditions or limiting values for noise tolerance may not be based on individual responses such as, for example, VCR (JANSEN 55, 57) SRR or the EMG response.

4. NOISE AND TASK DISTURBANCE

Noise can have an adverse effect on all mental and motor tasks involving the conveying of information in acoustic form. This is true both of aural tasks in the narrow sense (any form of acoustic communication, acoustic examination methods of doctors etc.) and of complex tasks, of which the auditory aspect represents only a part. As the noise level and the frequency composition of the stimuli, signals and information in question may vary a great deal, guide-levels can only be given for each case separately. Depending on auditory requirements, the necessary values may be much lower than the speech interference level (SIL, dB (A), AI).

So many tests have been carried out over the past forty years on the effects of noise on non-aural tasks that it would be impossible to refer to them in detail here. Critical and comprehensive accounts are to be found in the works of BERRIEN (6), DRYTER (68), PLUTCHIK (93), TEICHER et al. (121) and BROADBENT (10). Most laboratory tests deal with fundamental principles and have no direct relationship with usual conditions. They are intended either to reinforce or disprove a particular theory such as, for example, the theory of arousal (26, 43, 47, 68, 84, 107, 130, 137). Arousal not only implies increased alertness and susceptibility to respond to stimuli, but also increased sensitivity with regard to their effect. In many places of work a relationship has been found to exist between arousal as a result of noise and performance which may be represented by an upturned letter "U": with increased arousal performance improves until it reaches an optimum (represented by the tip of the upturned "U"), while further arousal (overarousal) leads to a deterioration in performance. According to HOCKEY (46), the optimum level of arousal for complex tasks is lower than that for simple tasks. Mc GRATH and HATCHER (78) state that simple tasks tend to be improved and difficult ones to deteriorate as a result of arousal.

According to the "filter theory" (BROADBENT (11)) only stimuli and information relating to work and occupational matters come to be considered from amid the excess of information available on the environment. New stimuli pass through the filter in order of loudness, information content, significance and motivational importance. Associated with this is the phenomenon of distraction, by which task-orientated concentration and alertness are disturbed, either briefly or over an extended period. Distraction varies from person to person. HÖRMANN and OSTERKAMP (48) found that people who are highly susceptible to disturbance are much more likely to perform their tasks badly than those who are not so easily disturbed. The work of SPRENG (117) suggests that task disturbance and annoyance brought about by noise are caused by malfunctioning of the central nervous information processing system.

Practical tests on the effects of a decrease in noise have produced varying results (for a brief synopsis, see the work of DIRECKX (24); however, it is already recognised that allowances have to be made for motivational factors when one assesses positive effects (WESTON and ADAMS (131)). A large number of tests suggest that alertness, concentration and creative thinking, in other words mental tasks, are greatly disturbed by noise. If school work is taken as an example of mental and psychomotor activity combined with concentrational effort, the tests conducted by BRUCKMAYER and LANG (14) on classroom disturbance caused by traffic noise provide useful information for establishing guide-levels. The effects of noise on class-room work, expressed as a percentage of the number of children affected are summarized below :

Effect of noise on class-room work as percentage of children affected

Noise level dB (A)	Windows open			Windows closed		
	undisturbed	disturbed	very disturbed	undisturbed	disturbed	very disturbed
40 - 45	100	0	0	3	3	94
45 - 50	73	22	5	50	10	40
50 - 55	50	40	10	0	21	79

These results reveal that the capacity to tolerate noise is lower when windows are closed than when they are open, and show the influence of the expection factors.

Including auditory functions in their studies (communication = speaking and understanding), BRUCKMAYER and LANG (14), found that 50 dB (A) represented a definite borderline between undisturbed and disturbed when windows were open; with windows closed this borderline was 45 dB (A).

This information on school children may be applied generally whenever the faculties most susceptible to disturbance - alertness, concentration and creative thinking, which are important in many professional, extra-professional and family activities - are being considered. On the basis of the results obtained one may conclude that a standard indoor value of 40 to 45 dB (A) should not be exceeded when such tasks are being performed. This should apply irrespective of whether a high degree of concentration, alertness and mental facility can be achieved at considerably higher noise levels, given the necessary motivation and tasks to which one is accustomed.

The wide array of information available on the effect of noise on task performance may be summarised as follows: noise can have an adverse, a neutral or a favourable effect on task performance. The following all have a bearing on this: volume of noise; frequency components; time structure; homogeneity and inhomogeneity; fluctuations in noise levels; depth of modulation; information content and significance; previous experiences; personal variables; degree of difficulty of the tasks; amount of mental, psychomotor and motor activity required; familiarity with tasks and with the environment in which the noise is made.

5. SPEECH INTERFERENCE AND ACOUSTIC ORIENTATION

5.1. The importance of Speech Communication

The reception of speech and other acoustic information with sufficient integrity is an important factor in the maintenance of human well-being. If health is defined in its modern sense as a complete state of well-being, the deprivation or degredation of an important channel whereby the individual is orientated to the world is a serious matter. That speech communication is important in everyday life is born out by the fact that reported speech interference is generally very highly correlated with the noise annoyance attitude (79, 108).

5.2. Speech characteristics

Human speech is highly variable in terms of intensity level and spectral content. The octave bands of main importance are 0.25, 0.5, 1 and 2 kHz though there are many systematic variations, not least those between male and female voices. The intensity and spectral characteristic for a given vocal effort varies with the production of vowels and consonants and with the manner in which a word or syllable is stressed. At conversational speeds syllable production lasts for approximately $^1/10$ of a second with on average $^1/8$ of a second separating adjacent syllables. Consonants are produced with lower acoustic power than vowels but tend to higher frequencies.

5.3. Reception of speech signals

The form in which speech signals will be received depends on several factors, the most important of which are set down in Reference 86.

They are:

1. The characteristics of the source
   for example the quality of enunciation of the speaker and his understanding of the language spoken.
2. The material being transmitted
   for example the familiarity of the listener with the language, dialect or content of the material in transmission.

3. The transmission path from talker to listener
   for example the degree of screening or reflection.

4. The relative position of talker, listener and noise source
   for example the degree to which the listener can make use of directional discrimination.

5. The noise level at the listener's ear relative to that at the talker's ear
   for example if the talker is not aware of the vocal compensation necessary.

6. The integrity of the listener's auditory system.

5.4. Masking and intelligibility

The case of the disruption of speech communication by extraneous and unwanted sound is a general case of the situation where sound of one spectral characteristic can be made to mask or effectively reduce the subjective loudness of another.

The noise level required to mask a consonant will depend greatly on the particular consonant involved (68). From this it can be inferred that the degree to which a significant part of a stream of speech is masked is dependent on the consonantal make up of the language sample in question. The findings on this subject are generally presented in terms of percentage intelligibility of phrases, words or sentences chosen and constructed in such a way that they provide a balanced sample of the language in use. This is possible because speech is interpreted by a combination of acoustic information and knowledge of language and context.

The results reported generally represent adequate intelligibility in the range of 95 - 99 % of sentences and 75 - 95 % of words or phrases (5, 68).

The assumption of knowledge of language and context must be coupled with others regarding age and enunciation for satisfactory conclusions to be made on intelligibility data. Children enunciate relatively badly and do not have such an extensive knowledge of language. Also the ability to interpret "noisy" speech is reduced after the age of 30. In addition over this age also there are more likely to be people with hearing impairments that would handicap interpretation of speech.

5.5. Variables

Apart from the consideration of acceptable percentage intelligibility there are other factors that must be considered in setting up criteria.

5.5.1. Distance from source to receiver

This is naturally important in the outdoor situation where the evidence available (99) indicates that the intensity of a speech signal decreases by an approximation to spherical spreading, 6 dB/octave. Indoors distance is less important since the listener in the average living or bedroom is assumed to be in the far (diffuse) field.

5.5.2. Vocal effort

Most reporters indicate three or more classes of vocal effort (129) corresponding to increasing voice level.

Reference 61 gives figures corresponding to 1 metre :

relaxed voice 55 dB (A)
normal voice 65 dB (A)
raised voice 71 dB (A)
very loud voice 77 dB (A)
shouting voice 83 dB (A)

The period for which the degree of vocal effort can be sustained is much reduced as the voice level rises.

5.5.3. Noise rating

There have been several schemes of noise measurement that were specially constructed for relating noise level to speech interference.

The most common are AI Articulation Index due to FRENCH and STEINBERG (33) and later simplified by KRYTER, and the SIL Speech Interference Level due to BERANEK (5).

Even in these simplified forms these systems are relatively complex relying, for example on measurement of noise levels in various frequency bands. They are also not well adapted to dealing with time varying noise levels.

It is no accident that the frequencies at which human hearing is most acute coincide largely with the most important speech frequencies. Since dB (A) is widely used for other community noise situations it seems sensible to adapt it to this situation. ROBINSON notes (99) that dB (A) is suitable for all but the most unlikely environmental noises, those with rising spectra. Such noises are unusual and it seems most unlikely that these characteristics would be preserved after atmospheric propagation or transmission into buildings. The percentage speech interference due to a given equivalent level (Leq) of time varying noise is marginally lower than due to a steady state noise (52, 132). As the variability of the external noise increases the degree of speech interference decreases for a given value of Leq. It has been shown that Leq in dB (A) is practically as good a predictor of speech interference as any other single number noise scale (120).

5.6. Criteria

There have been a considerable number of criteria published relating to acceptable speech communications. The figures mentioned below are chosen for their relevance to the situation discussed at the first meeting of the EEC national experts on noise.

5.6.1. Outdoor Levels

ROBINSON in (99) indicates that conversation is possible in a noise level of 54 dB (A) at 4 metres. This implies that a level of 66 dB (A) would just allow conversation at 1m.

The distinction is frequently made between what is acceptable for a normal conversation and what is preferable for a relaxed conversation. Figure 1 (51, 52) provides data on the noise levels permitting tolerable normal conversation and preferable relaxed conversation at a distance of 1m.

65 dB (A) allows tolerable conversation (sentence intelligibility - 95 %)

55 dB (A) allows preferable relaxed conversation (sentence intelligibility - 99 %)

An additional conversational effort line (68) has been applied to Figure 1 showing to what extent the speaker can make effort to allow a conversation rather than merely pass a message.

Figure 2 replotted from reference 86 indicates the percentage sentence intelligibility at a distance of 1 metre for various noise levels expressed in Leq dB (A). 95 % sentence intelligibility is at Leq = 66 dB (A). This rapid change in speech quality over the 65 - 70 dB (A) threshold is clear.

5.6.2. Indoor levels

Interference with speech communication inside a home is almost certainly less tolerable than that outside. That speech interference occurs inside the home is indicated by the proportion of people reporting that noise disturbed listening to TV or radio (79; 108).

The acoustic environment inside a dwelling is defined by its structure and furnishings and by the noise sources within and without the building. In the average room with an absorbtion of 300 Sabines the near field extends to just over 1 metre. Any likely listener will be in the diffuse field.

Figure 3 indicates that the likely criteria values of 99 % or 100 % intelligibility are reached at 55 and 45 dB (A). The lower figure corresponds to the upper range of levels suggested as acceptable for homes. In figure 3 the noise levels quoted are indoor levels and allowance must be made for attenuation through open or closed windows if an external noise level is to be assessed.

5.6.3. Acoustic privacy

The extent to which environmental noise shields private conversation should not be overlooked. A level of 50 dB (A) is necessary to provide complete acoustic privacy beyond 15 m from the talker (normal conversational voices out of doors). 42 dB (A) would allow the conversation to be easily understood at this distance. In practice shielding and random orientation effects are present and reduce the extent to which conversation can be casually "overheard".

6. ANNOYANCE AND COMMUNITY REACTION

Field studies of the effect of environmental noise exposure on populations not involved in the process producing the noise generally utilize the concept of annoyance. The noise annoyance attitude is used as the independent variable in creating functional models relating exposure to effect and has tended to be used as a concept to quantify the general reaction to unwanted noise.

In the international situation the relative meaning of the concept of annoyance must be adequately defined in each particular context even if the meaning is not exactly equivalent in each case.

As a basic model of the cause effect relationship it seems reasonable to accept that the perception of an unwanted noise leads to a degree of annoyance the nature and intensity of which is determined by a number of physical or psycho-social factors (8).

Annoyance due to noise has been described as the adverse subjective feeling or attitudinal reaction aroused by unwanted noise (82), and in a non-specialist context as "... the resentment we feel at an intrusion (by noise) into a physical privacy that we have, for the moment, marked out as our own ..." (89).

In certain countries and administrative regions it is feasible for aggrieved persons to make various kinds of direct approach to the source of the noise nuisance or the responsible branch of government. This is particularly true in countries where the legal framework often makes legal action possible against sources of aircraft noise nuisance. For this reason there has arisen a body of methodology relating noise exposure to likely community reaction (102, 136). The types of action considered range from sporadic individual complaint to concerted legal action so that in this context community action includes all kinds of viable complaint, whether personal, written, telephoned or by signed petition or individual and group approaches to government and law suit.

6.1. Measurement of annòyance

The techniques used in investigative field work on noise using social survey methods frequently define the annoyance attitude by default by leaving the exact meaning of annoyance to the respondent. It is common for the phrase "annoyed, bothered or disturbed" to be used as overlapping synonymes.

Complex psycho-social attitude measurement techniques have been used in this field (18, 79, 108) but it is evident (81) that the simple categoric scale which requests the respondent to make a choice between stated degrees of annoyance is generally adequate.

6.2. Factors relating to annoyance

The discussion paper (71) presented at the first meeting of E.E.C. national noise experts listed the factors having a bearing on the annoyance attitude. These are explained below. It must be realized that the annoyance concept involves the integration of these effects some of which may be highly inter-related. The integration also takes place in the time domain since past experience and future expectation are important.

6.2.1. Acoustic Factors

The manner in which the train of physical stimuli impinge upon the observer is determined primarily by acoustic factors. The intensity or sound pressure level of the noise on the relevant frequency weighting scale is of course important. It is claimed that in the case of aircraft noise the peak level is the only important factor given certain other broad conditions (103, 104). The frequency content of a noise relates strongly to its perceptability especially if pure tones are present. A great deal of work has been done in developing various frequency rating scales suitable for specific source group (reviewed in 68), but it is now apparent that the ease of use and broad applicability of the "A" weighting scale is leading to its general acceptance for community noise considerations. The duration of a stimulus is a significant factor in annoyance (108). Some of the more advanced noise rating techniques take this into account by using duration corrections in rating single events (eg. EPN dB) while in others the duration or number of events is integrated by summing incident energy over a given time period (eg. Leq).

Sonic booms and other more mundane impulses have characteristic rapid initial rise times. The duration of the rise time has been shown to have an effect on the startle reaction and hence on annoyance (85). It is for this reason that impulsive noise is generally a special category in noise rating scales.

The nature of any other time dependence of the noise level is an annoyance related factor. The aircraft noise situation results in high peak levels in predominantly low or moderate background levels. Road traffic noise is characterized by levels varying over a moderate range, while industrial noise may be cyclic, intermittent or steady state.

The prevailing background noise level is used on the available evidence (9) as a reference in public judgment of the acceptability of intending noises.

6.2.2. Activities disturbed

The measurement of annoyance is frequently accomplished by accounting various activities disturbed by the noise under investigation. The frequency and severity of disturbance and the annoyance caused thereby have been shown to be very closely related to the amount of annoyance reported (80). Figure 4 indicates how certain specific types of activity disturbance are related to average noise annoyance (108). Figure 5 shows the type of questions that have been used in a self completion questionnaire and assess degrees of activity disturbance and aircraft noise annoyance (76).

Activities commonly reported as being disturbed by environmental noise are:

Sleep disturbance, by prevention or waking.

Interference with rest, or relaxation (indoor or outdoor).

Interference with speech communication, in conversation, use of telephone, or appreciation of T.V. or radio.

Disturbance of hobbies, sports, recreations or household activities. Other items mentioned are startle, the vibration of furniture or dwellings or T.V. picture interference. Very few survey respondents mention any other type of activity disturbance.

6.2.3. Situational variables

Situational variables relate to the likelihood and extent of noise exposure and activity disturbance. The time of day of exposure is an obvious factor, the greatest sensitivity to sleep disturbance and lowest ambient noise levels naturally occurring during night-time hours. A survey of traffic noise exposures (49) showed that a large majority of those who were disturbed by noise away from their place of employment were disturbed inside their home. If measurement and prediction techniques deal with outdoor noise levels, seasonal and cultural differences must be considered to take account of preferred life styles and more specifically attenuation provided by typical windows. This last factor would undoubtedly be affected by climate. The type of neighbourhood is also a determining factor in noise annoyance. Persons choosing to live in city centres apparently tolerate higher traffic noise levels than those domiciled in country districts.

6.2.4. Attitudinal factors

The dependence of an individual's noise annoyance score on various attitudinal factors is strong. It is agreed that the personal characteristics of the listener act upon the subjective judgement of the character of the noise to produce the attitude we call annoyance (8, 9, 82, 103).

The respondent's feelings towards the preventability of the sound are important. If he feels that those responsible for the production and propagation of the noise are unconcerned about those affected by it or if he feels that the noise could feasibly be prevented or reduced his adverse reaction will be exacerbated.

The attitude towards the usefulness of the equipment or process generating the noise is also important. If the primary product or effect is personally valued or used noise may be more readily tolerated as a by product.

The response of an exposed person to the meaning or information content of an unwanted sound will also determine the extent of the annoyance reaction. If there is an element of fear or a belief in a danger to health annoyance will tend to increase.

Pure sociological variables such as sex, age and socio-economic status do not appear to have a consistent effect on noise annoyance (8, 81).

6.3. Noise measurement and annoyance prediction

The justification for the study of the relationship between noise and exposure is that there should result a reliable means of predicting the likely degree of annoyance (or community reaction) from knowledge of an appropriately measured noise exposure. This is to enable planning and control measures to be carried out. Table I shows a sample of some of the aircraft noise exposure indices that have been postulated in recent years. The variety in terms of specific expressions is large though there is an underlying unity in that all take account of intensity and number of events in a manner that is effectively similar.

The major disadvantage of all of these indices is that none are very successful in predicting an individual's response to aircraft noise exposure. The NNI index developed from studies around London Heathrow Airport (79, 108) is correlated only moderately with individual annoyance scores, the simple product moment correlation coefficient being about 0.5. The correlation with group average annoyance scores, however, approaches unity. Thus these indices are adequate for predicting the mean reaction of large groups of people but do not allow assertions to be made about an individual's likely reaction. A result of this condition is that since a significant number of people at a low noise exposure and a large number of people at a moderate noise exposure are often highly annoyed, the majority of seriously annoyed persons may not be living in high exposure areas. The noise exposure index only explains approximately one quarter of the variance in individual annoyance scores. The consequence of non-noise level dependent effects may be large if they are not randomly distributed (81). The incorporation of psycho-social attitude variables into the annoyance/exposure regression can raise the multiple correlation coefficient based on individual scores to nearly 0.8, (18) but the functional utility of this operation is low since these attitudinal factors cannot themselves be predicted and attempts to modify them on a large scale are unlikely to be effective or politically acceptable.

The profusion of national aircraft noise annoyance scales suggests systematic differences in noise tolerance between nations. The recent Swedish study comparing Dutch, German and Japanese data concluded that given a similar range of number of overflights per day the average aircraft noise annoyance reaction was dependent only on peak dB (A) levels in each of these countries (104). A comparative study of the tolerance of traffic noise in Sweden and Italy (58) suggested that the overall level of tolerance of traffic noise was higher in Italy. The question of adaptation to noise exposure is frequently raised but does not appear to be a significant factor. It is stated (15) that those who are not used to a noise will tend increasingly to resent it and that the higher the noise level the less likely it is that adaptation will occur.

6.4. Community reaction

The importance of the prediction of community reaction is generally recognised, but methods and community reaction indices vary from country to country. Some of these indices have been refined over the past twenty years from case studies (102, 136) and the resulting index Community Noise Equivalent Level (CNEL) bears most of the significant features incorporated during this time. CNEL is defined as an "A" weighted equivalent energy level with normalisation factors applied to take account of most of the acoustic and situational factors mentioned in (82). Table II and figure 6 indicate the correction factors and criteria. It is relevant to note that no reaction is expected at or below CNEL = 55 dB (A). This represents an equivalent level (L_{eq}) of the intruding noise 7 dB above the pre-existing background noise level (L_{90}) and 2 dB above the median ambient noise level (L_{50}). Widespread complaints are expected at L_{90} + 17 dB (A) and vigorous action at L_{90} + 33 dB (A). (17).

A similar approach is involved with the International Standards Organisation's (ISO) draft recommendation 1996 (53) which is now accepted as an approved recommendation for the assessment of noise with respect to community response. The recommendation suggests the use of an Leq dB (A) measure for the intruding noise which is normalised by application of correction factors for:

nature of signal (impulsive, steady or intermittent)
unusual spectrum (Noise Rating Curves)
time of day
type of district

The rated sound level (L_r) so obtained is compared with a criterion level derived from pre-existing background levels or land use. The amount by which the rated sound level exceeds the criterion level is related to the expected community response:

L_r exceeds criterion level by	Estimated Community Response	
	Category	Description
0	None	No observed reaction
5	Little	Sporadic complaints
10	Medium	Widespread complaints
15	Strong	Threats of community action
20	Very strong	Vigorous community action

(indoors - 10 dB windows open,
- 15 dB windows closed)

The rate and form of complaint about noise has been suggested as a means of assessing noise impact. The relationship between complaint and annoyance has been studied and it is evident that the percentage of a population making a complaint is a function of the number of persons highly annoyed in that population, Figure 7 (18). Though such social factors as socioeconomic status, and degree of education play no part in determining the extent of an individual's noise annoyance reaction, they relate to the propensity to complain about aircraft noise (8, 82, 109).

6.5. Criteria

A consequence of the almost complete lack of standardisation of annoyance and noise exposure measurement schemes is that national results are seldom directly comparable. The most suitable intermediate noise measure where comparison is possible is the dB (A) equivalent energy level. This is the measure suggested for use in criteria at the first meeting of national noise experts.

The effect variables of noise exposure are annoyance, complaint and community reaction. Annoyance is the most difficult to portray. Figure 8 indicates how average noise annoyance as measured around London Heathrow Airport varies with noise exposure in terms of Leq in dB (A). The correlation of the group mean annoyance scores with exposure is high but Figure 9 reveals how at an Leq of 57 dB (A) 20 % of the population were highly annoyed while Figure 8 indicates that at this level of aircraft noise exposure the average annoyance rating is between "Not at all" and "A little" annoyed. 50 % of the population became highly annoyed at an Leq of approximately 70 dB (A).

Mc KENNEL states that, at a score of 3.5 as measured on this annoyance scale (81), noise annoyance becomes the salient attitude in the individual's attitude to his neighbourhood. Figure 10 indicates how this occurs at an Leq level of approximately 60 - 65 dB (A) although these attitudes start to become more common at levels 10 dB lower.

Figure 11 indicates the percentage of persons reporting each type of activity disturbance investigated as a function of noise level. Noise annoyance then is not neatly distributed with a clearly defined threshold value. Both annoyance and the disturbed activities on which annoyance is methodologically based have a broad distribution in the population at a given noise exposure.

The data used for prediction of community response has been re-analysed in terms of a normalised equivalent energy level that is referred to as a Day Night Sound Level (L_{dn}) by reason of the 10 dB night weighting that is applied (52). Figure 12 indicates that the relationship is similar to that of CNEL to expected community reaction. The percentage of a population who will register some form of complaint is related to the percentage of persons highly annoyed in the population. In the summary

Figure 13 (95), these response factors are related to the noise exposure in dB (A) L_{dn} and to the community reaction that might be expected.

There is little published work that indicates criteria for purely impulsive noises such as sonic booms, but it has been suggested (52) that the weekly summation of sonic boom peak pressures should not exceed 1.0 pounds per square foot.

6.6. Land use

Noise annoyance criteria have in certain cases been translated into recommendations or regulations for land usage. One approach is to rank various categories of land usage by sensitivity to environmental noise. The SAE ARP 1114 (112) ranks family dwellings and cultural and medical facilities among the most sensitive and agriculture, forestry and transportation facilities as among the least sensitive. The UK Department of the Environment (92) has used the NNI index to codify policy towards housing planning applications around London Heathrow Airport.

60 NNI	No new dwellings
59 - 40 NNI	No major new developments. Infilling allowed with appropriate sound insulation.
35 - 39 NNI	Permission not to be refused on grounds of noise alone.

Problems frequently arise when indices and planning rules developed for a particular context are used to determine planning attitudes in other situations.

6.7. Recommendations

The recommending of levels for noise standards is complicated with considerations of feasibility which depend upon the availability of suitable technology and the political will to regulate and improve a situation. The problem is also confused by the diversity and unpredictability of human response to noise exposure. A level of exposure that is reasonably acceptable for the majority of a population may be intolerable for a numerically large minority of that population.

For this reason the setting of levels of acceptable noise exposure must either involve the acceptance that large numbers will continue to be affected even if the situation is improved for the majority or the inclusion of the large factors of safety that are necessary if there is to be no effect on any but a few of a population.

For this reason two standard levels or goals are here suggested.

1. The level that is apparently tolerable to the majority of the population.
2. The level that is clearly acceptable to the majority of the population.

6.7.1. Community reaction

In terms of community response these two criteria seem to suggest levels of 65 - 70 and 55 - 60 Leq dB (A).

CRITERION	NOISE LEVEL	EXPECTED REACTION RANGE
Tolerable	65- 70 Leq dB (A)	Sporadic complaints to widespread complaints and single threats of legal action.
Clearly acceptable	50-55 Leq dB (A)	No reaction although noise is generally noticeable to possibility of (from Figure 6) sporadic complaints.

6.7.2. Annoyance and attitude to noise

At Leq dB (A) Levels of 60 - 65 the average annoyance score is in the upper part of the "Little-Moderately Annoyed" range, though up to 40 % of the population report themselves highly annoyed. A clearly more acceptable range is 50 - 55 Leq dB (A) with average annoyance ratings between "A Little" and "Not at All". 20 % or less are highly annoyed.

CRITERION	NOISE LEVEL	EXPECTED ANNOYANCE LEVELS
Tolerable	60-65 Leq dB (A)	Average Annoyance "A Little" to "Moderately" 40 % "Highly Annoyed"
Clearly acceptable	50-55 Leq dB (A)	Average Annoyance "Not at All" to "A Little" 20 % "Highly Annoyed"

(from Figures 8 and 9)

The manner in which the attitude towards noise becomes salient among other attitudes towards a person's neighbourhood can be seen form Figure 7. Above 65 Leq dB (A), the noise is the most common phenomenon mentioned and the most common reason given for wanting to move from the area. In the range 50 - 55 Leq dB (A) both of these attitudinal responses begin to rise above threshold levels.

CRITERION	NOISE LEVEL	EXPECTED SIGNIFICANCE OF NOISE IN ATTITUDE FORMATION
Tolerable	65 Leq dB (A)	Noise becomes most important factor in attitude to neighbourhood
Clearly acceptable	50-55 Leq dB (A)	Attitudinal significance of noise begins to increase

6.8. Conclusion

The ranges 60 - 65 Leq dB (A) and 50 - 55 Leq dB (A) are clearly indicated for the two categories of criteria tolerable and clearly acceptable. The higher level is no doubt more achievable but it is important that a standard representing a near perfect situation to be achieved in the future should be adopted to provide a suitable reference point for judging present levels and aiming future work.

7. CONCLUSIONS

On the basis of the observation and researches which have been summarized in the preceding chapters, it is possible to identify a number of effects which are dangerous or harmful to the health of the population, and to define criteria for the occurrence of each of them.

The risk can thus be stated specifically and recommendations can be made on the basis of dose-effect type knowledge.

The harmful effects which are such as to entail intervention by the public authorities may be summarized as follows:

7.1. Risk of rupture of the ear-drum:

Ear-drum rupture has been observed in explosions during which excess pressure at the ear-drum occurred in a very brief time, below 1 second and usually below 10^{-5} seconds.

The relationship between sudden excess pressure and ear-drum rupture has been demonstrated by observations taken in wartime and by experiments on corpses and animals. The criterion for the occurrence of such a rupture is an excess pressure level of 7 psi. The excess pressure level guaranteeing that this effect will not occur may be fixed at 5 psi.

Other authorities fix this safety level at 0.1 atmospheres of sudden excess pressure. On the other hand, sound pressure being produced progressively over a period longer than 1 second can also cause ear-drum rupture if it reaches levels of 156 dB and over.

Experience in the field of occupational medicine indicates that it is wise to set the safety limit at 140 dB, having regard to the differences in individual reactions, particularly as a function of age.

Recommendations should be drawn up so that no person may be exposed under any circumstances to either of these risks of ear-drum rupture.

7.2. Risk of sudden deafness:

The appearance of unilateral or bilateral sudden deafness has been described by several German, French and Japanese authorities.

The circumstances in which this particular type of deafness occur are as yet still inadequately defined. It is known, however, that it occurs in people who are occupationally exposed to noise and in noisy surroundings with a sound pressure level permanently higher than 90 decibels.

Adequate recommendations can be produced for people who are occupationally exposed. The general public, on the other hand, should never be exposed to a permanent noise level of 90 dB and over.

7.3. Permanent hearing loss

Daily exposure to sound pressure levels over 85 dB (A) causes progressive hearing loss, of a permanent character, in people occupationally exposed.

ISO recommendation R 1999 defines the protective conditions which should be applied so as to prevent permanent hearing loss. It defines a sound pressure level equivalent (Leq) expressed in dB (A), which can also be applied to interrupted noises, provided that they last more than 1 second. The safety level to prevent the occurrence of permanent hearing loss is Leq = 80 dB (A).

This standard also applies to the general public, and recommendations should be drawn up to ensure that members of the public are never exposed to an equivalent level higher than 80 dB (A).

7.4. Sleep disturbance

The interfereing effects of noise on sleep have been demonstrated by epidemiological surveys and experimental studies with continous electroencephalography. The continuous equivalent level which constitutes a threshold above which the pattern of sleep is disturbed is between

40 dB (A) and 50 dB (A) in the room. Furthermore, the threshold for activation of the central nervous system by a single noise superimposed on a continuous background noise may be estimated at 10 dB (A).

The continuous equivalent level which would not affect sleep at all may thus be estimated at between 30 dB (A) and 35 dB (A), while the maximum sound level should not exceed the continuous equivalent level by more than 10 dB (A). These figures refer to the inside of the bedroom.

7.5. Interference with relaxation

The criteria defining the threshold above which noise interferes with sleep, i.e. a continuous equivalent level (24) of 30 dB (A) to 35 dB (A) in the room, may perhaps also be used when organizing the protection of relaxation. However, the public authorities may be led to decide whether such protection should be restricted to specific and particularly sensitive groups, such as invalids, convalescants, and inmates of old peoples' homes.

For the reasons given in the section on interference with sleep the recommendation must include the provision that the maximum sound level must not exceed by more than 10 dB (A) the continuous equivalent level selected as the criterion for interference of noise with relaxation.

7.6. Interference with speech

Research undertaken into the interference of noise with conversation have been directed principally towards ascertaining the percentage intelligibility of the sentences or words selected to represent a balanced sample of the language.

Two evaluation systems have been proposed on the relation beween the level of ambient noise and interference with conversation: the articulation index, and the speech interference level.

However, a good prediction of the interference of noise with speech communication can be established on the basis of a continuous equivalent level expressed in dB (A).

Criteria of the dose-effect type relating to the interference of noise with speech communication have to take account of varying situations, according to whether the conversation is being held inside or outside a building or whether it is normal or confidential.

It may be said that out of doors a continuous equivalent level of 65 dB (A) permits normal conversation at a distance of 1 metre and that an equivalent level of 55 dB (A) permits an extended confidential conversation at the same distance.

Inside buildings, equivalent levels between 55 dB (A) and 45 dB (A) permit normal conversation at 1 metre, normal conversation being understood as 99 to 100 % sentence intelligibility.

For confidential conversations, normal hearing is possible at an equivalent level of 42 dB (A).

7.7. The influence of noise on community reactions

Annoyance due to the intrusion of an undesirable noise into a private environment at a given moment may be the cause of opposition from large sections of the population of a given community. Various types of reactions may be observed, from individual complaints to joint legal action, with intermediate stages such as personal representations, telephone calls or petitions to the public authorities.

Various research operations have attempted to prepare indices permitting prediction of the degree of annoyance of a certain percentage of the population concerned. The principal drawback of such indices is that none of them permits really certain prediction, the correlation coefficient being of the order of 0.5.

In the interests of standardization ISO recommendation R 1996 suggests the use of a continuous equivalent level.

The establishment of acceptable noise exposure levels entails either accepting that a large part of the population will continue to suffer disturbance even if the situation is improved for the majority, of else including major safety factors, which are indispensable given a desire to eliminate all annoyance effects except perhaps on a tiny sector of the population.

For this reason we suggest that two objectives be defined:

1) a level which is apparently tolerable by the majority of the population,

2) a level which is clearly acceptable to the majority of the population.

In the tolerable level is fixed at an equivalent level of 65 to 70 dB (A), sporadic complaints, sometimes complaints over wide areas, and a few threats of legal action will probably ensue.

If the clearly acceptable level is fixed at an equivalent level of 50 to 55 dB (A) no protests at all or at the very most a few sporadic complaints will ensue.

The annoyance will be moderate, i.e. approximately 40 % of the population will be considerably annoyed, if the equivalent level is set at 60 to 65 dB (A).

The annoyance will be slight, i.e. about 20 % of the population will be considerably annoyed, if the equivalent level is set at 50 to 55 dB (A).

We consider that our recommendations should be based on these last two criteria:
an equivalent level (Leq) of 60 to 65 dB (A) is easier to attain,
an equivalent level (Leq) of 50 to 55 dB (A) represents a more satisfactory situation which could be achieved in the future.

It **will be** for the responsible authorities to draw up recommendations taking account of the actual conditions of each country and the reactions of each population.

The objective of the studies summarized above was to deduce from the total body of observation and research usable,limit values, observance of which would effectively protect populations against the effects of noise on health.

TABLE I **Some national aircraft noise exposure indices**

TITLE	ABBREVIATION	COUNTRY OF ORIGIN	DEFINITION	NOTE
Noise and number index	NNI	U.K.	$\bar{L}_{PNmax} + 15 \log N - 80$	
Störindex	$\bar{Q}$	Germany	$(1/\alpha) \log (1/T) \int_0^T 10^{\alpha Q(t)} dt$	1
Indices de classification	R	France	$\bar{L}_{PNmax} - 16 + 10 \log (N/960) + 5 \log \xi$	2
Annoyance index	AI	Australia	$10 \log \sum 10^{L_{PNmax}/10}$	
Noisiness index	$\overline{NI}$	South Africa	$10 \log \sum \{K^2 (t/T) 10^{L_A/10}\}$	3
Noise exposure	L_{exp}	Netherlands	$20 \log \sum (k \cdot 10^{L_A/15}) - 106$	4
Aircraft exposure level	L_E	ISO	$10 \log \sum 10^{L_{EPN}/10} + 10$	

Notes:

1. The value of α and the choice of the measure Q (t) are left free, but in practice the former is take to be 1/13.3 and the latter to be L_{PN} or L_A.
2. ξ is the annual average runway utilization factor.
3. K^2 is a time-of-day factor, 1 from 08.00 to 18.00 hrs.
4. k is a time-of-day factor, the same as K^2 in the South African formula.

(from 99).

TABLE II

Corrections to be Added to the Measured Communtiy Noise Equivalent Level (CNEL) to Obtained Normalized CNEL

Type of Correction	Description	Amount of Correction to be Added to Measured CNEL in dB
Seasonal Correction	Summer (or year-round operation)	0
	Winter only (or windows always closed)	- 5
Correction for out-door residual Noise Level	Quiet suburban or rural community (remote from large cities and from industrial activity and trucking).	+ 10
	Normal suburban community (not located near industrial activity).	+ 5
	Urban residential community (not immediately adjacent to heavily travelled roads and industrial areas).	0
	Noisy urban residential community (near relatively busy roads or industrial areas).	- 5
	Very noisy urban residential community.	- 10
Correction for Previous Exposure and Community Attitudes	No prior experience with the intruding noise	+ 5
	Community has had some previous exposure to intruding noise but little effort is being made to control the noise. This correction may also be applied in a situation where the community has not been exposed to the noise previously, but the people are aware that bona fide efforts are being made to control the noise.	0
	Community has had considerable previous exposure to the intruding noise and the noise marker's relations with the community are good.	- 5
	Community aware that operation causing noise is very necessary and it will not conitnue indefinitely. This correction can be applied for an operation of limited duration and under emergency circumstances.	-10
Pure Tone or Impulse	No pure tone or impulsive character	0
	Pure tone or impulsive character present	+ 5

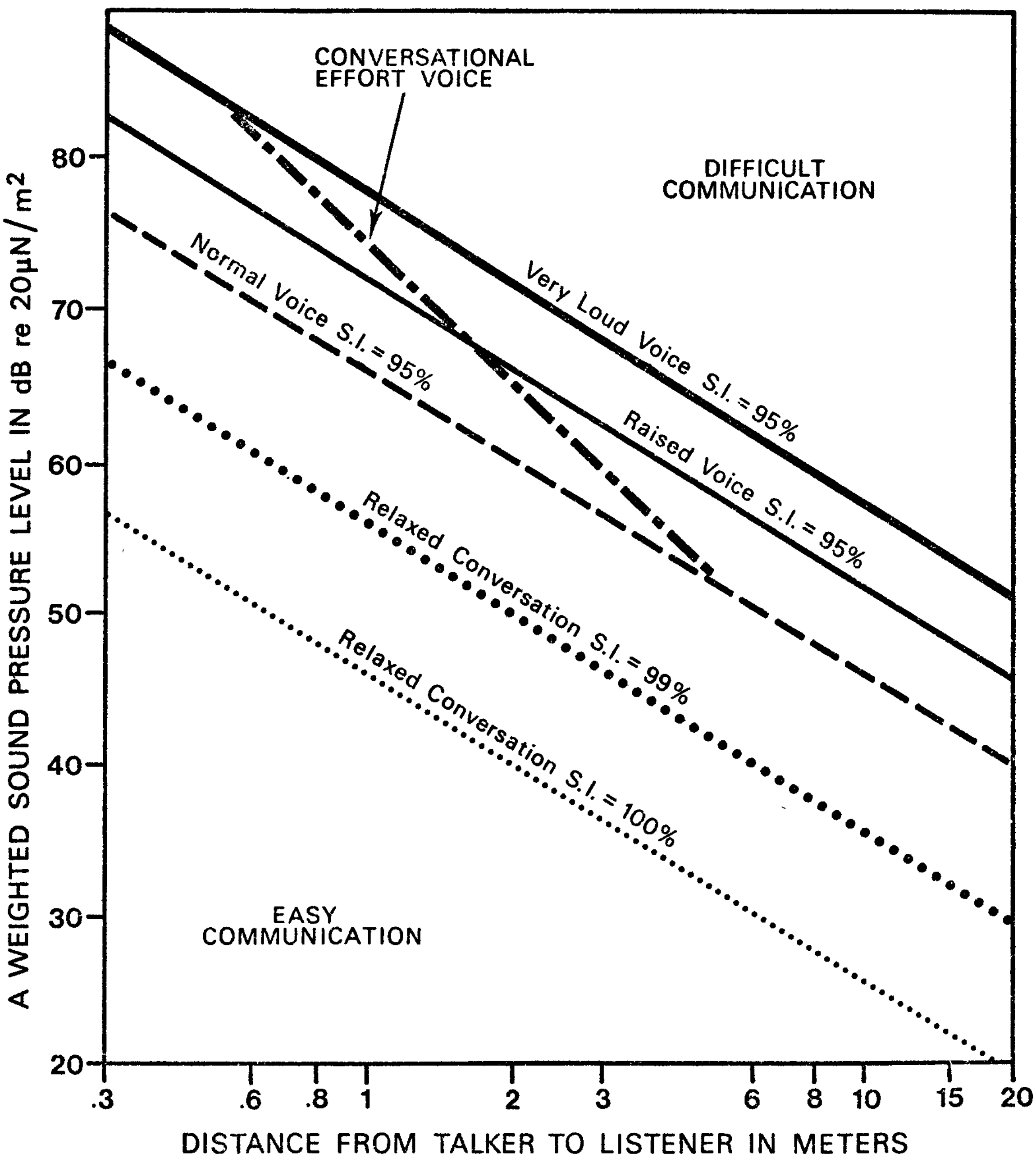


Figure 1 Distance at which speech can be understood as a Function of Distance, Noise Level, Voice Level and expected Sentence Intelligibility (S.I.)

replotted from (51,52)
and (68)

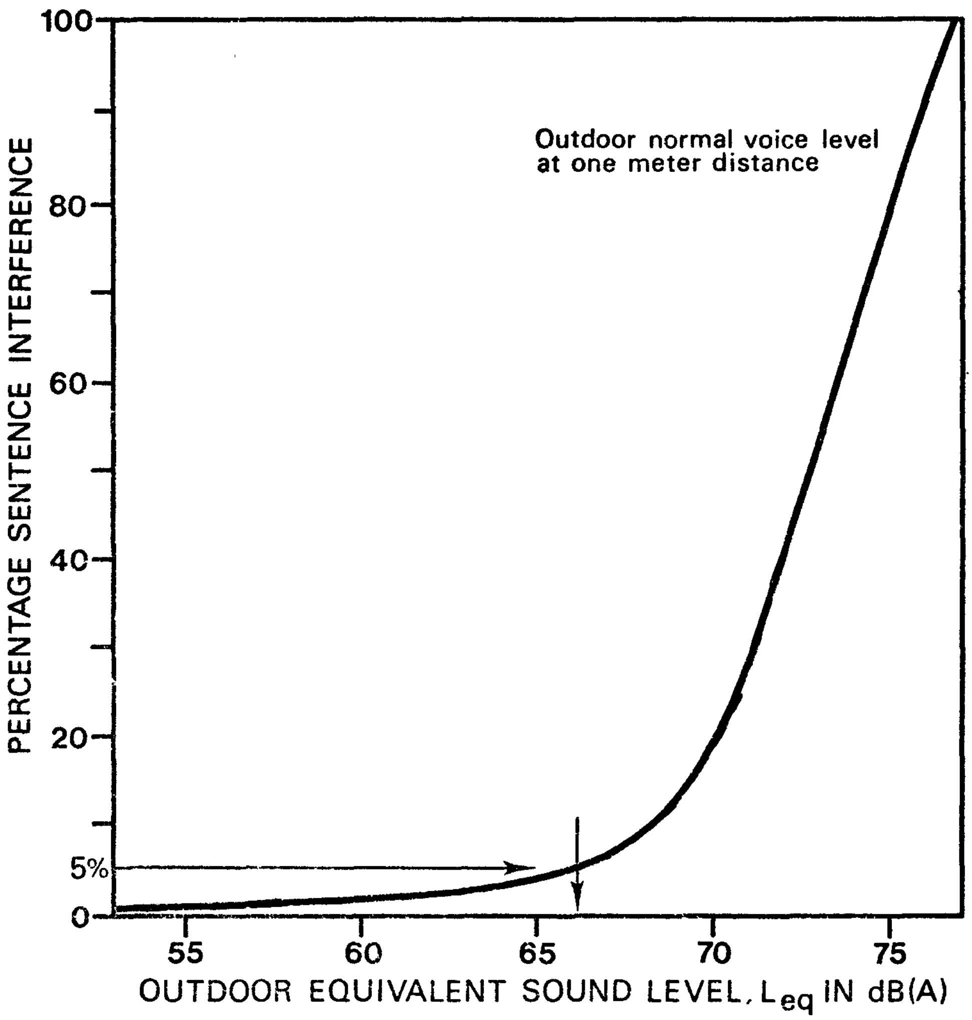


Figure 2 Percentage Sentence Interference as a Function of Outdoor Equivalent Sound Level, L_{eq} in dB(A)

replotted from (86)

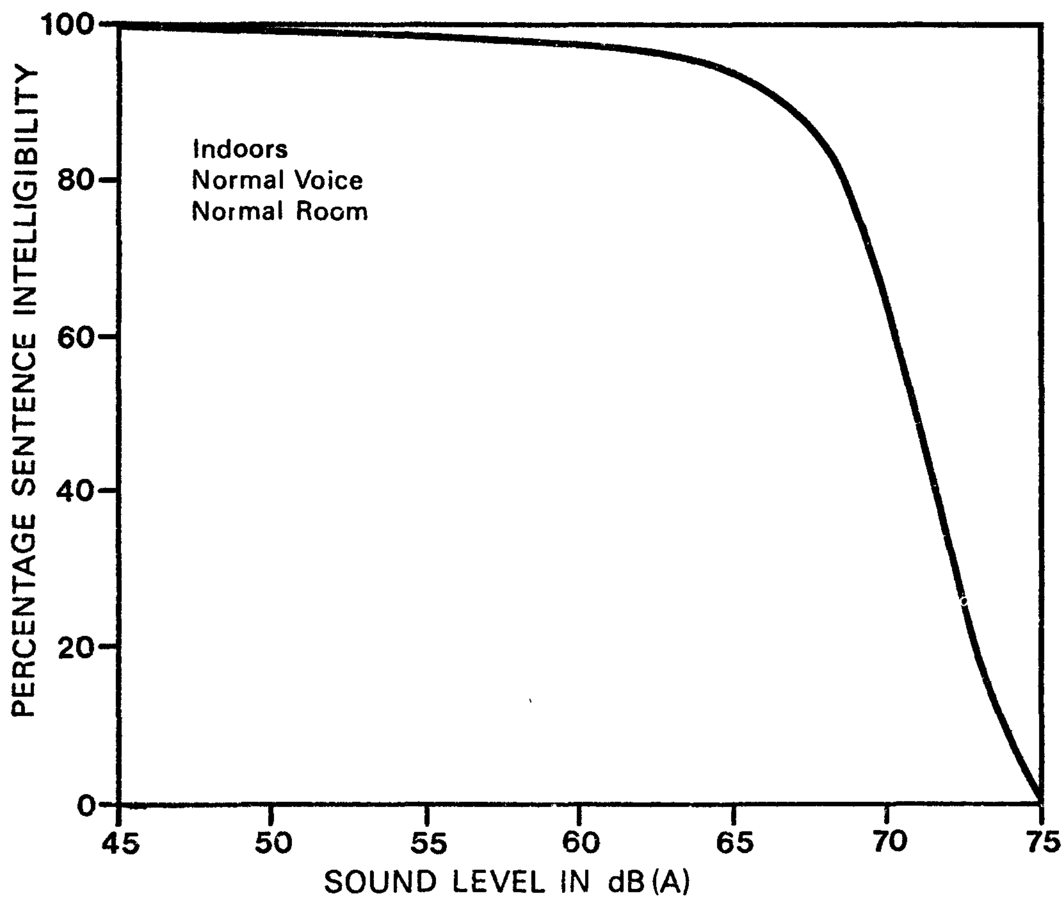


Figure 3 Sentence Intelligibility as a Function of Sound Level for Normal Voice in the Indoor Situation

Relaxed conversation would be 10 dB lower

replotted from (52,99)

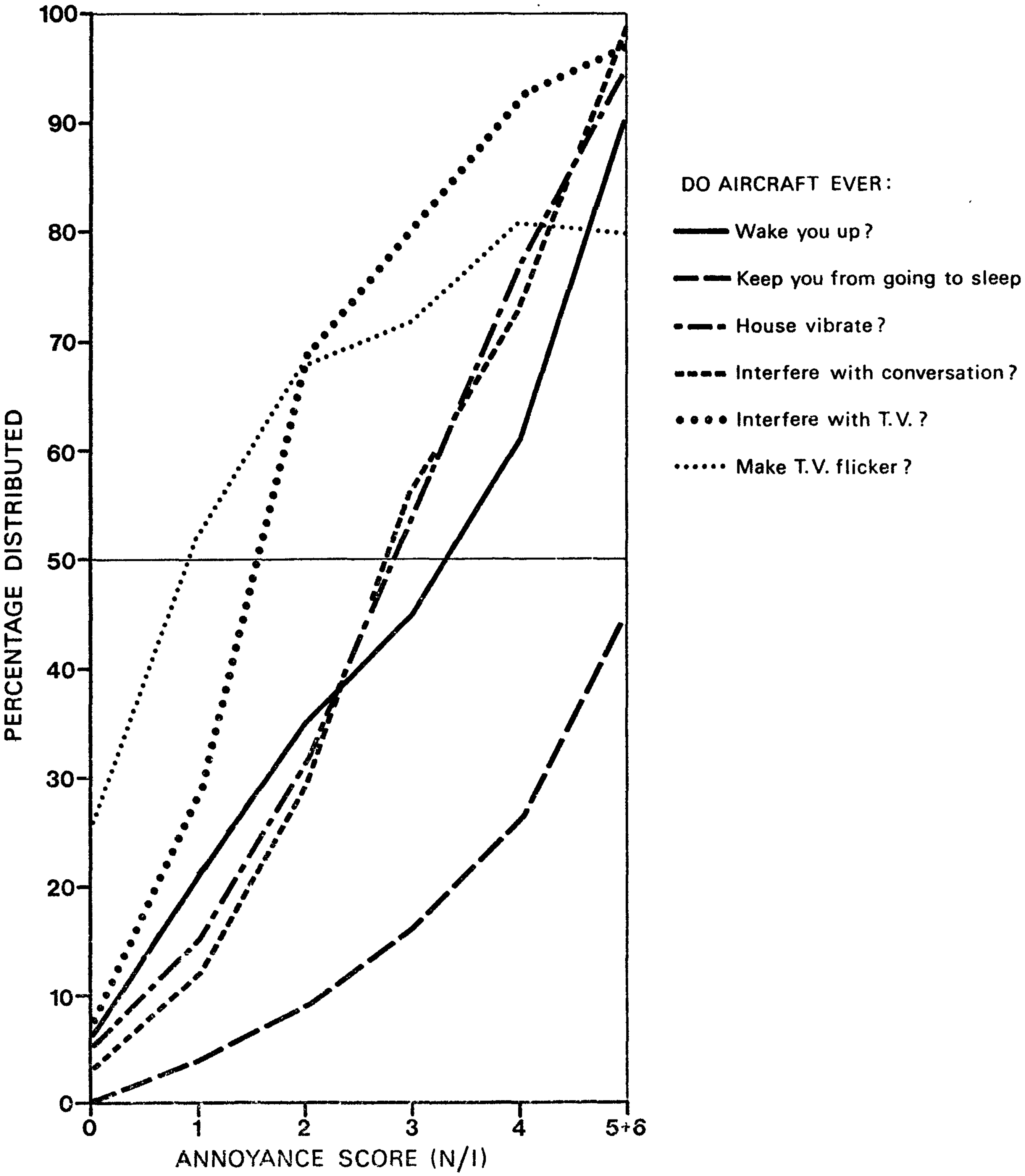


Figure 4. Proportion experiencing each type of disturbance at various levels of annoyance

from (108)

6 How much does the noise from aircraft annoy or bother you?

Very much	
Moderately	
A little	
Not at all	
Don't know	

a) Self rating categoric scale

7 In this question we are asking if noise from aircraft ever disturbs you in any particular ways. Please answer for each way. If your answer is 'yes' to the first part of a question please complete the second part of the question by telling us how much the disturbance annoys you when it happens.

Does noise from aircraft ever	1	2	If YES how much does it annoy you when it happens?				
	YES	NO	VERY MUCH	MODER-ATELY	A LITTLE	NOT AT ALL	DON'T KNOW
i Startle you?			1	2	3	4	5
ii Keep you from going to sleep?							
iii Wake you up?							
iv * Interfere with listening to TV or radio?							
v * Make the TV picture flicker?							
vi Make the house vibrate or shake ?							
vii Interfere with conversation ?							
viii Disturb your rest or relaxation ?							
ix Interfere with or disturb any other activity ? If yes, please specify.							

b) Activity disturbed scale

Figure 5 Aircraft noise annoyance scales

from 76

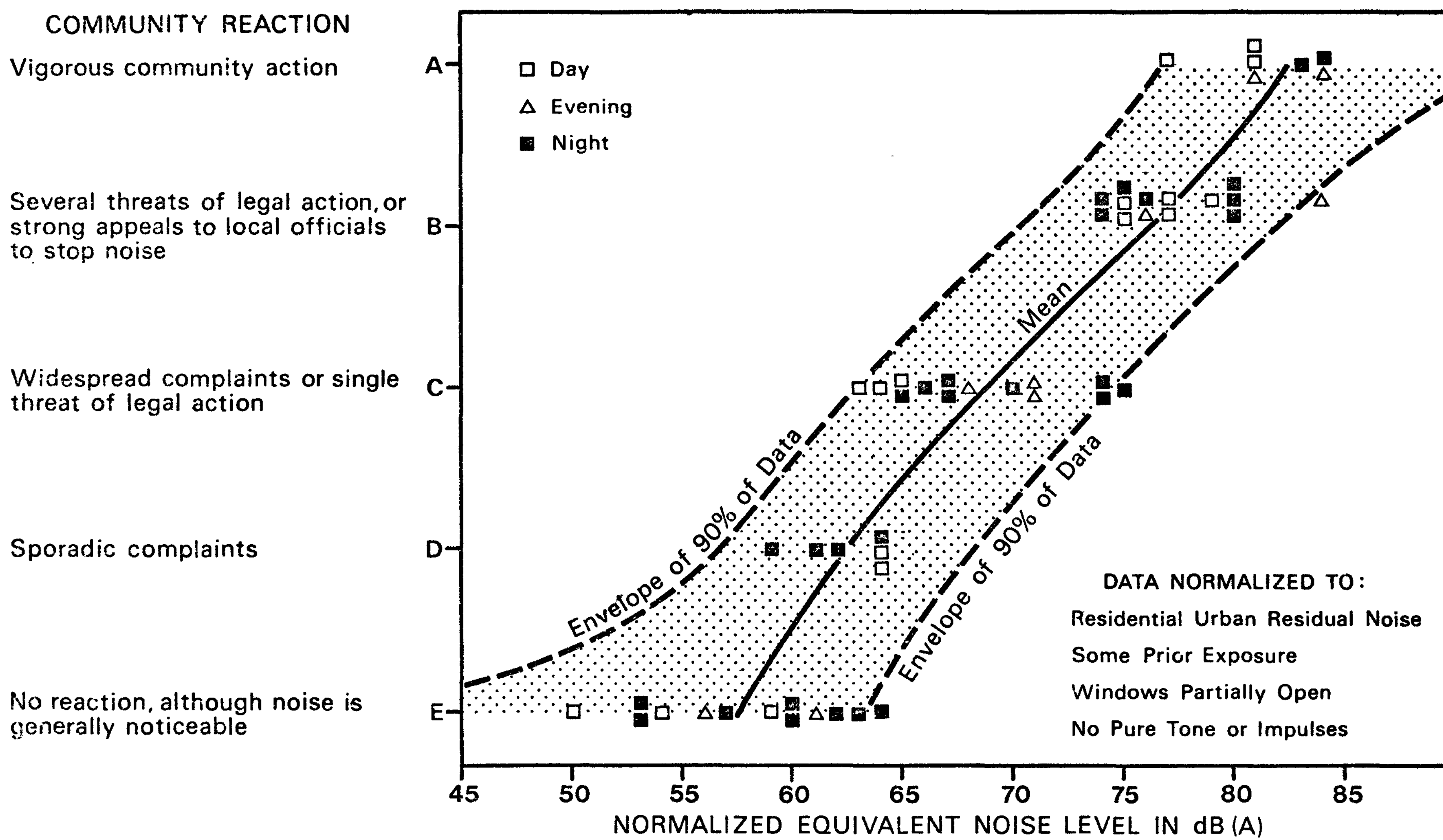


Figure 6. Community Reaction to Intrusive Noises of Many Types as a Function of the Normalized Noise Level Using Original Procedures of Rosenblith and Stevens

from (17)

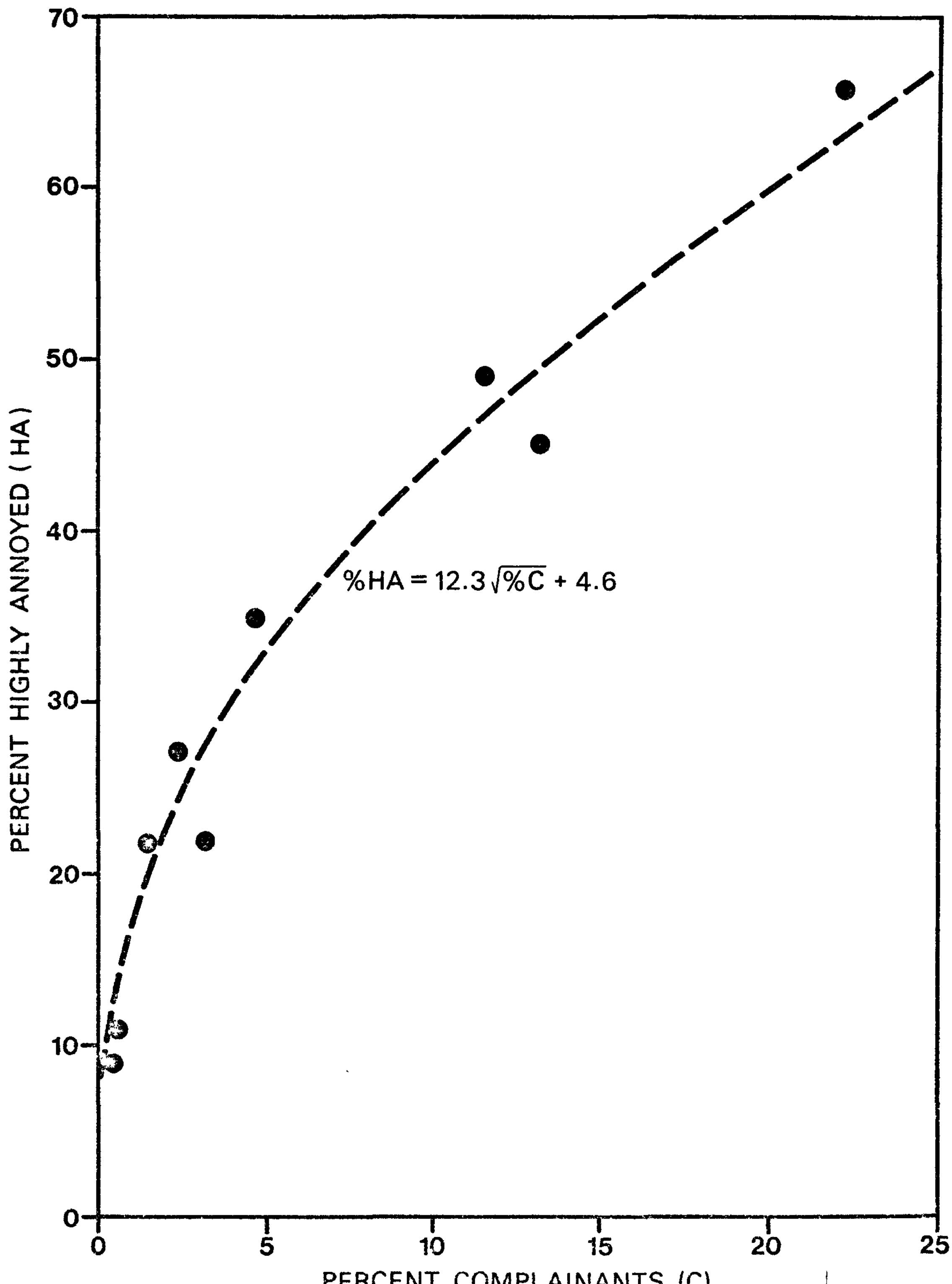


Figure 7. Percentage of Highly Annoyed as a Function of Percent Complainants

from (18)

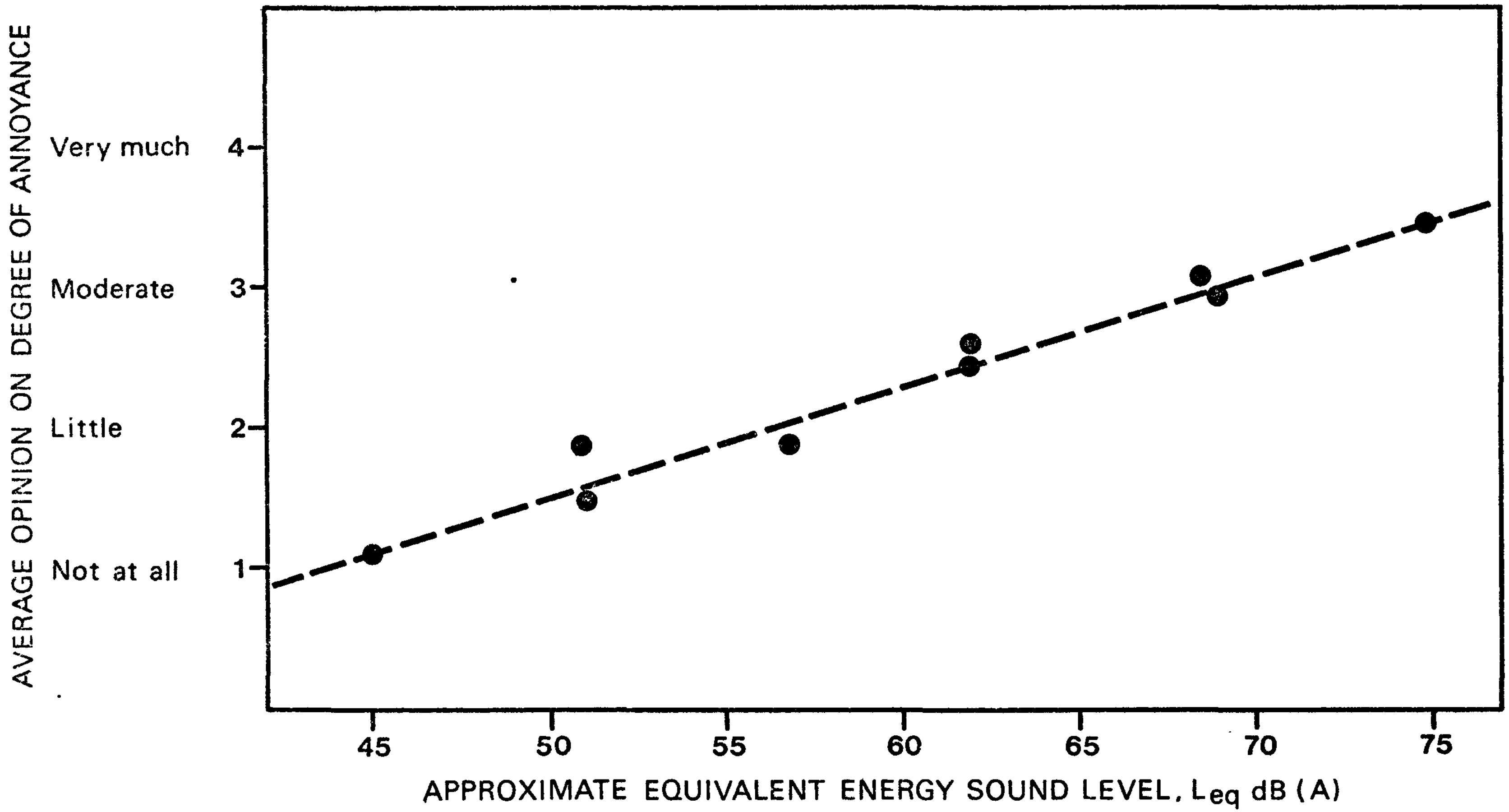


Figure 8. Average Degree of Annoyance as a Function of the Approximate Equivalent Energy Noise Level – Results of First London Heathrow Survey

replotted from (52)

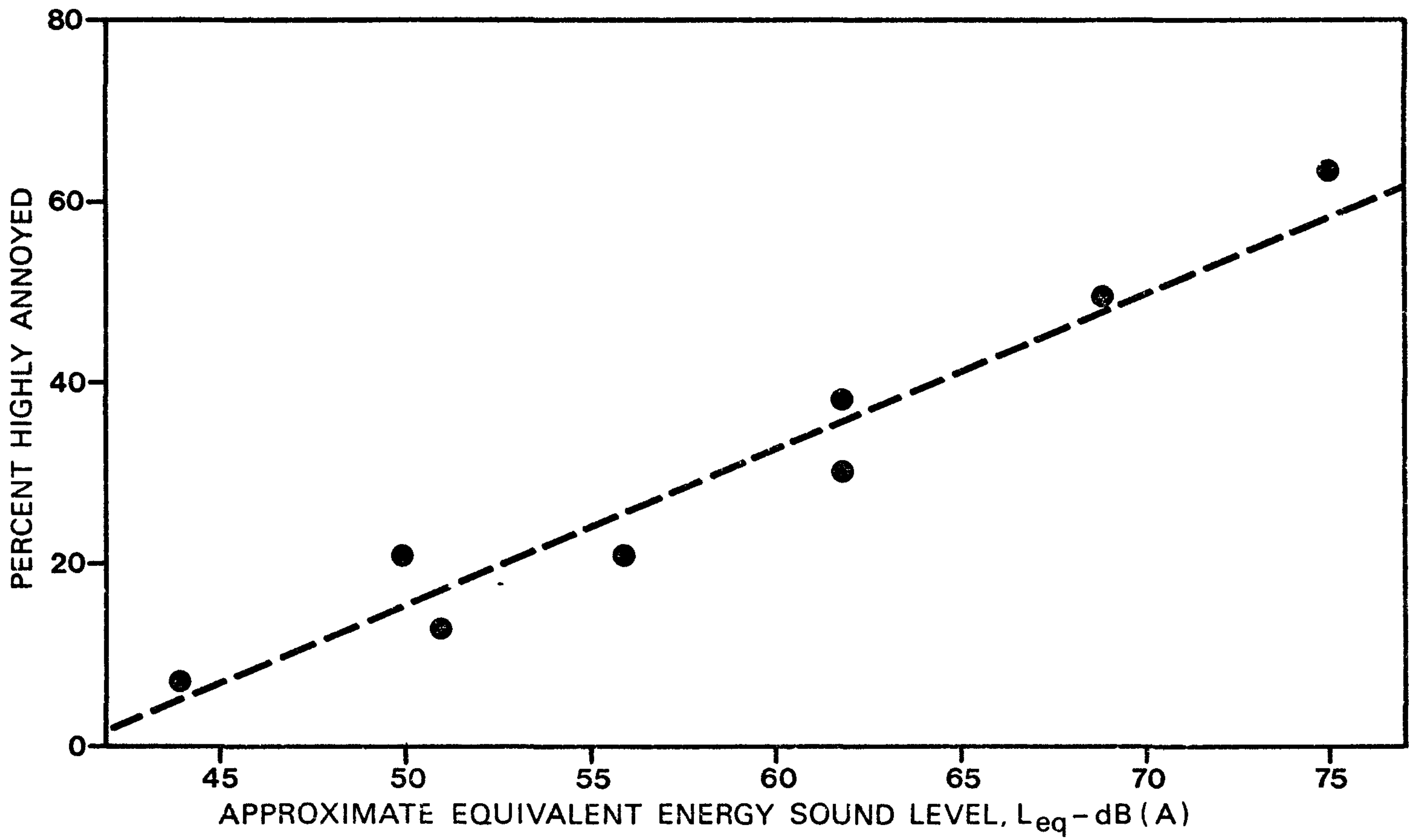
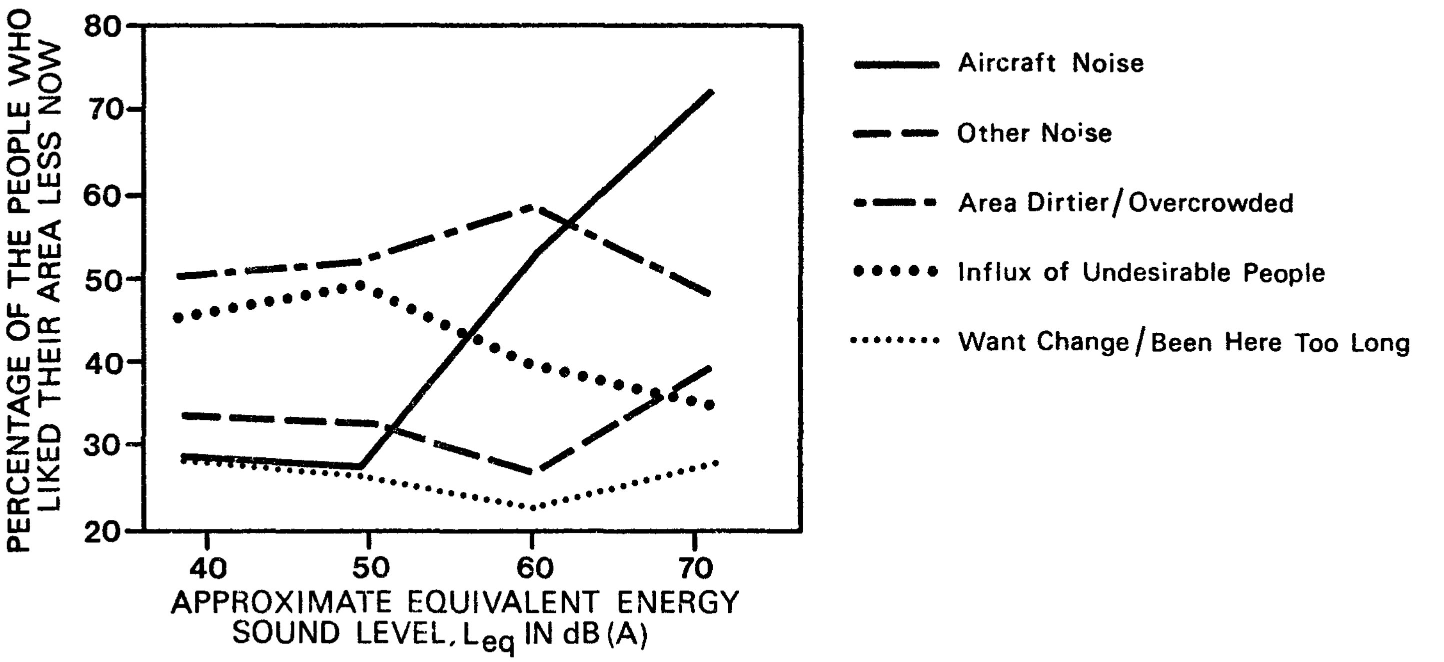
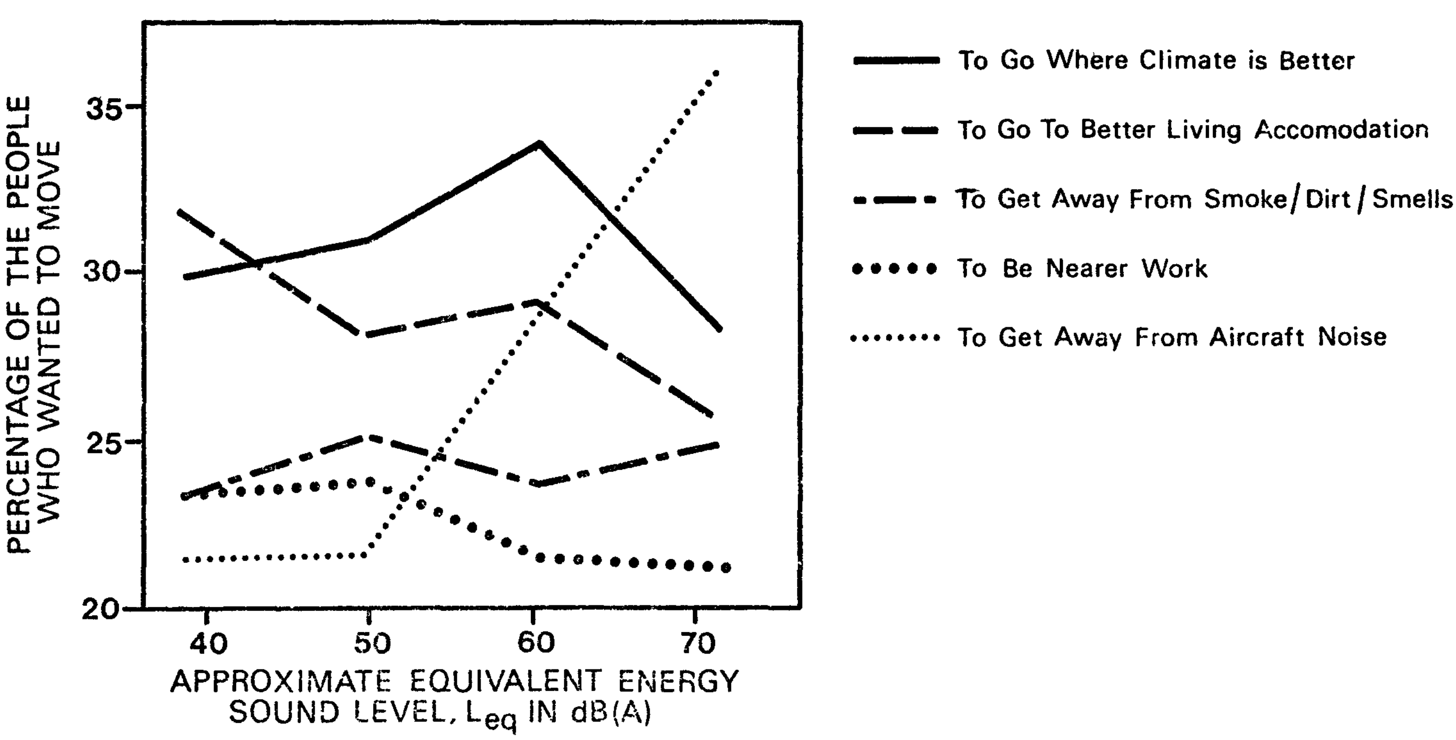


Figure 9. Percentage Highly Annoyed as Function of Approximate Equivalent Energy Noise Level-Results of First London Heathrow Survey

replotted from (52)



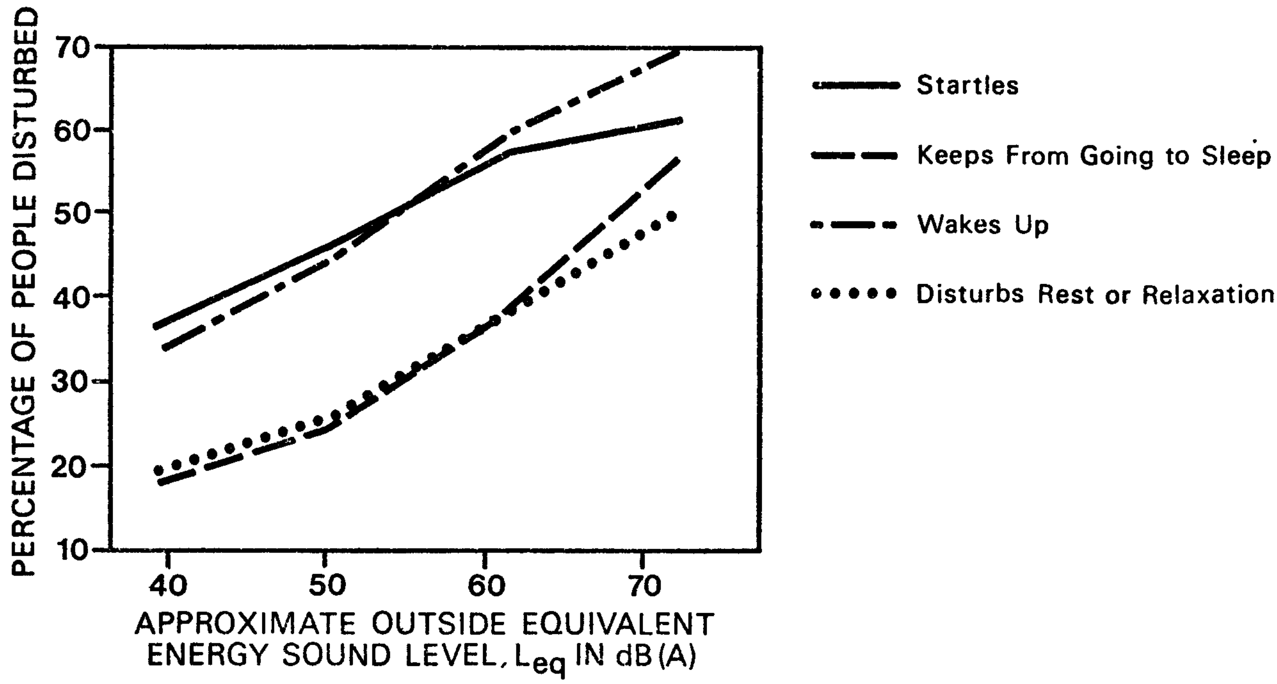
Percentage of people liking their area less now than in the past for various reasons



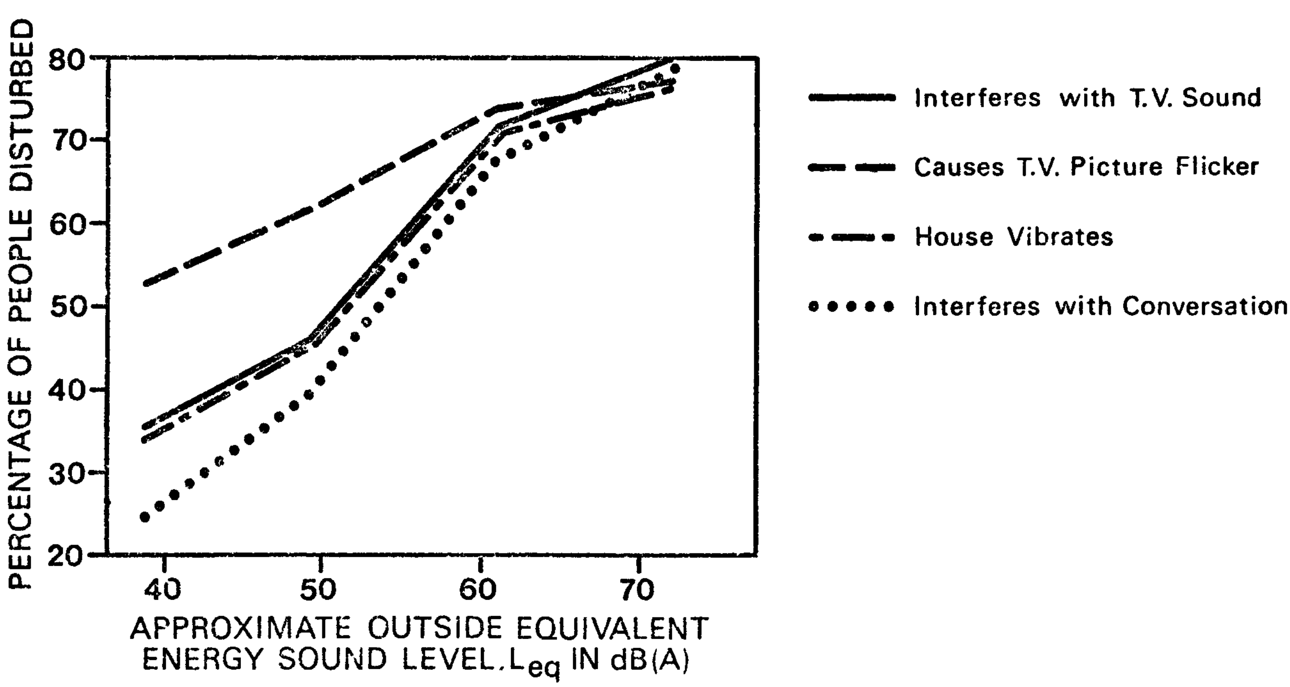
Percentage of people giving particular reasons for wanting to move

Figure 10. Attitude to area and noise exposure

replotted from (52)



Percentage of People Disturbed by Aircraft Noise for Various Types of Reasons Concerned With Rest and Sleep



Percentage of People Disturbed by Aircraft Noise for Various Types of Reasons Concerned With Domestic Factors

Figure 11. Percentages of Persons Reporting Various Types of Activity Disturbance as a Function of Aircraft Noise Level

replotted from (52)

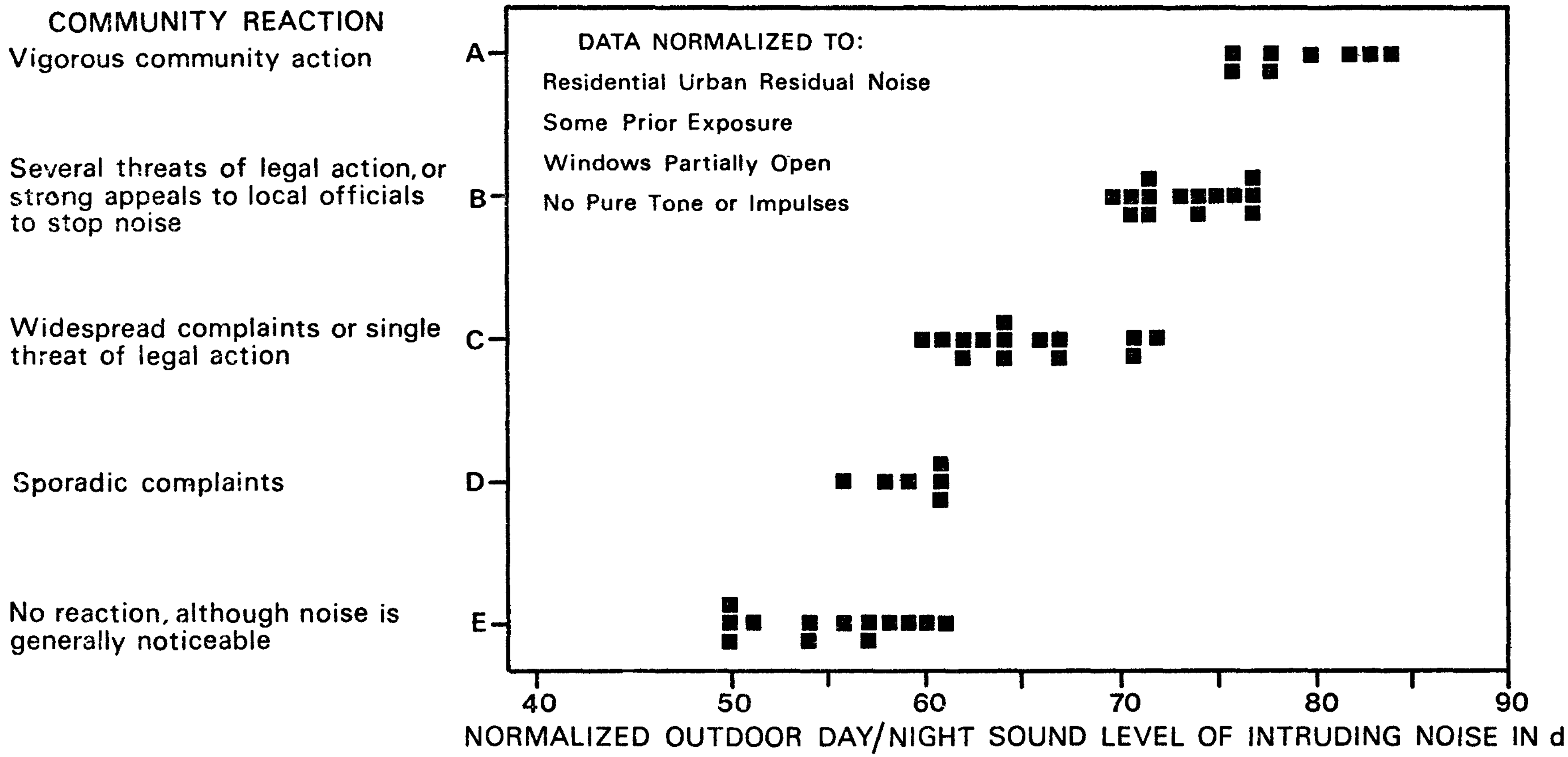


Figure 12. Community Reaction to Intensive Noises of Many Types as a Function of the Normalized Outdoor Day/Night Sound Level of the Intruding Noise, L_{dn} in dB(A)

from (52)

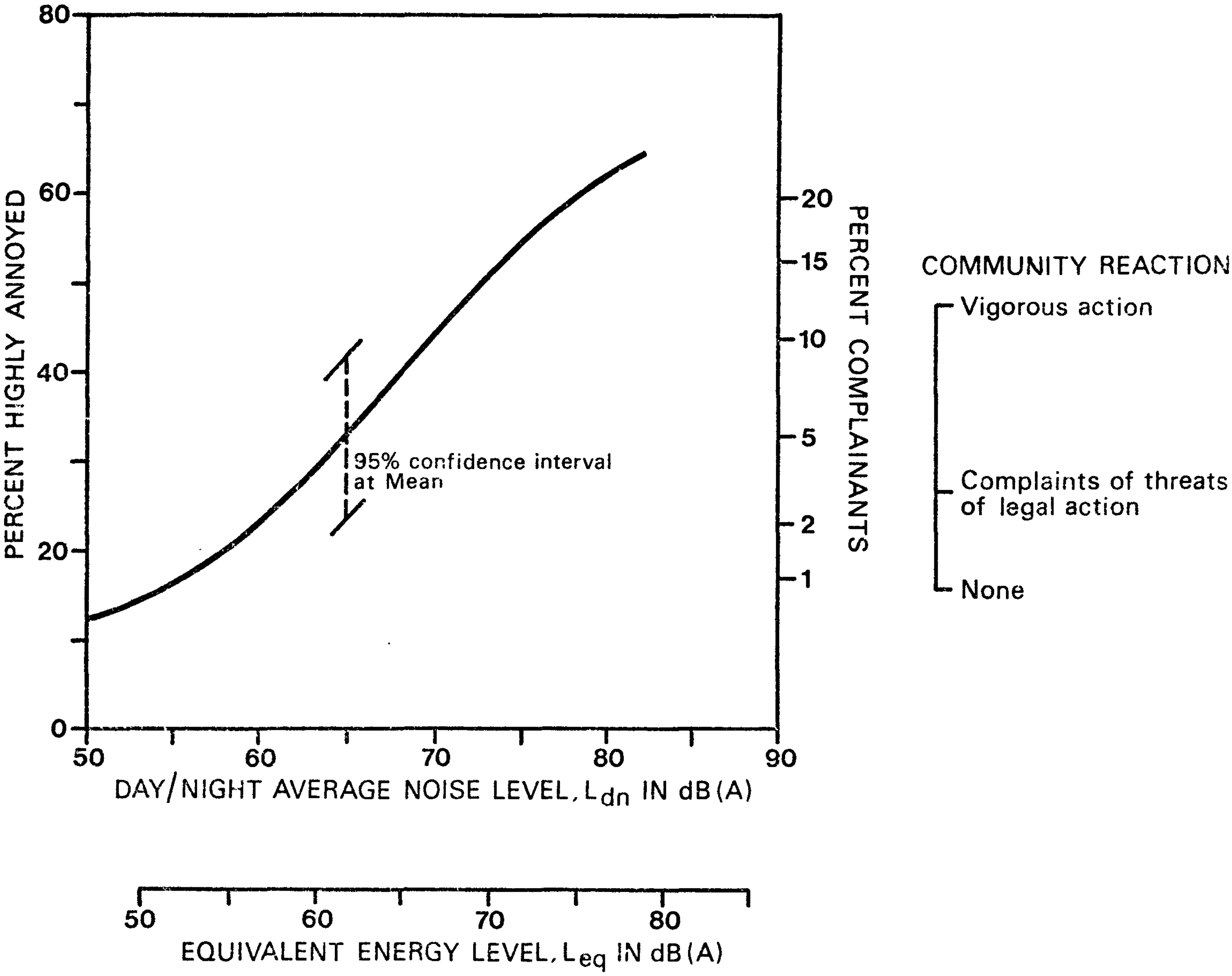


Figure 13. Intercomparison of Various Measures of Individual Annoyance and Community Reaction as a Function of the Day/Night Average Noise Level, L_{dn} in dB(A) and Equivalent Energy Level, L_{eq} in dB(A)

from (95)

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