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SYMPOSIUM REPORT

Noise-induced extraaural effects

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The paper presents roughly the state of the art concerning the extraaural effects of noise. Noise-related alterations comprize primary effects that occur during the period of noise exposure (*e.g.* speech interference, sleep disorders, altered autonomous functions), secondary effects that are mediated by the primary effects (annoyance, degraded well-being and performance), and tertiary effects, *i.e.* long-term health effects (hypertension, cardiovascular diseases). Where the causal relations between noise and acute primary effects are evident and very likely for cumulative responses and secondary effects, it was as yet impossible to determine causal relations between health disorders and noise exposure despite well founded hypotheses. The difficulties to determine causal relations increase with the time lag between the on-set of noise exposure and the manifestation of an effect in question. The reasons are manifold. Where the primary effects were almost exclusively studied in the well controlled experimental situation in the laboratory, the assumed health effects cannot be studied but in the field, where the acoustical situation varies considerably and where many other acoustical and non-acoustical environmental agents may enhance, attenuate or even mask the primary and secondary responses to the noise in question but might nevertheless —as non-specific stimuli— contribute to the genesis and manifestation of health effects. Another important factor is habituation, that causes a reduction of primary and secondary responses with time. The significance of these contributors in view of the hypothesized health effects must be elucidated in future studies. Other topics for future research are discussed as well.

Keywords: Communication, Autonomous responses, Sleep disturbances, Performance, Health effects, Future research

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1. INTRODUCTION

Due to conscious perception and interference with various activities noise is the most annoyant environmental pollutant. At present, concerning transportation noise, 40% of the European population are exposed to rating levels of at least 55 dBA and 20% to 65 dBA and more. Noise load is expected to increase considerably during the next few years, more during the night-time hours than during the day.[1)]

The present paper concerns the extraaural effects of noise, it aims not at the presentation of detailed results but tries to determine general trends and needs for future research.

A reasonable and sufficient categorization of the extraaural effects of noise is achieved when both, functional and temporal criteria are simultaneously applied. Functional criteria distinguish *e.g.* between autonomous responses, impairments of rest and sleep, communication, performance, psychosocial well-being, and health. Temporal criteria refer to the delay of a given response to the onset of noise exposure.

- Primary effects occur during exposure periods, *e.g.* during bedtime or during a workshift. They are again subdivided into acute effects that occur shortly after noise onset (*e.g.* awakening) and cumulative effects that represent the aggregated acute responses over the entire exposure period (*e.g.* excretion of stress hormones over a night or over a workshift).

- Secondary effects are the consequence of the primary effects; they occur already during and often exceed the exposure period (*e.g.* annoyance due to impaired communication) or they appear after the exposure period (*e.g.* tiredness after noise-induced sleep disturbances).
- Tertiary effects or health disorders: Primary and secondary responses are often tolerated for some time. In the long run, however, they are supposed to contribute to the genesis and manifestation of multifactorial chronic diseases, to chronic annoyance, and to permanent behavioral alterations. The hypothesized pathways of these developments are depicted in Fig. 1.

Apart from hearing loss and from the masking of acoustical informations, effects of noise are generally non-specific. The elucidation of causal relationships becomes therefore difficult and even impossible, the more the greater the time lag between the onset of noise exposure and the manifestation of an effect in question.

Alterations that occur shortly after stimulus onset (acute reactions, *e.g.* awakenings) are obviously evoked by noise and their registration is most appropriate for the evaluation of the effects of distinct (intermittent) noise events. There are, however, already some doubts concerning the quantitative aspects of causal relations for the cumulative responses that are used to describe the effects of rather continuous noises over the entire exposure periods. The effects of a defined noise cannot be separated from the responses to other acoustical and non-acoustical stimuli that occur during the same time and evoke similar non-specific acute effects (*e.g.* increased release and excretion of stress hormones).

The uncertainty about causal linkages is somewhat greater for the secondary effects where the relations with the assumed health effects remain on the level of —well founded— hypotheses.[2,3] Adopting, however, the WHO definition[4] of health as 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' the extraaural effects of noise, the impairments of rest and sleep, of communication, psychosocial well-being, and performance are clearly classified as health effects.[5]

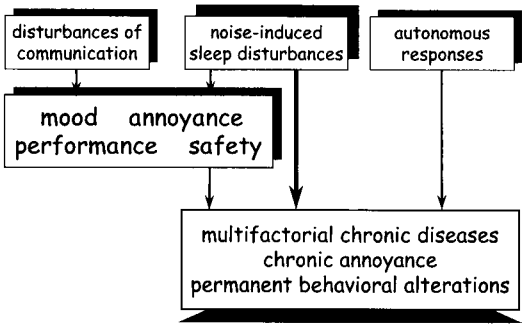

Fig. 1 Primary, secondary and tertiary effects of noise and their hypothesized connections.

2. PRIMARY EFFECTS

2.1 Communication

Ninety percent of informations are visually perceived, but the auditory channel is undoubtedly more important and essential for the mental and social development of man. This statement is supported by the fact that persons blind from birth achieve more often higher education levels than deaf people. The main reasons are the permanently open auditory channel and the fact that hearing does not presuppose directed attention.

Acoustical communication can be disturbed by at least 3 different mechanisms, directly by masking and indirectly by distraction and by noise-induced hearing loss.

- Masking: Masking is a pure physical phenomenon and —apart from aural effects (*e.g.* noise-induced hearing loss, NIHL)— a specific noise effect. Noise interferes with the relevant acoustical information which then becomes indetectable for the listener.
- Distraction: Various noises, particularly those with high information content (speech, music *etc.*), distract attention and the relevant acoustical information, that is otherwise well detectable is no longer consciously perceived.
- Noise-induced hearing loss: The detection of a relevant acoustical information becomes difficult in case of noise-induced hearing loss (as well as in case of reduced hearing acuity of any other reason).

The consequences of impaired communication are manifold. Annoyance is almost unavoidable if conversations either face-to-face or via telephone are repetitively interrupted and these effects are much stronger in case of interrupted one-way communication, if, for instance, the news provided by radio or television broadcasts are masked and if these informations are then definitely lost. Performance is

impaired if task-relevant acoustical (verbal and non-verbal) informations are no longer or only partly perceived (see section 3.1). Eventually, masked warning signals may even cause (*i.e.* not prevent) accidents. Epidemiological studies have indeed shown an increased frequency of accidents at higher noise levels. However, as none of these studies have taken into account possible confounders the results are not convincing but they anyway support the hypothesis that has yet to be examined.

Research in this area was initially focused on the determination of signal-to-noise ratios that are required for sufficient communication. The relationships between speech intelligibility and background noise levels have been well quantified and the behavior of speakers and listeners in different acoustical situations were intensively studied.[6] At present, the interest is directed to special acoustical situations, to persons who exert special activities, to those who are handicapped by blindness or by impaired hearing and to children who need a greater signal-to-noise ratio for perfect hearing during language acquisition.[7] Additionally, great effort is spent on hearing protection while preserving or fascilitating the ability to perceive acoustical informations[8] and on the design of signals that are essential for work and safety.[9]

2.2 Autonomous Responses

The autonomous (physiological or vegetative) responses correspond to activations of the sympathetic branch of the autonomous nervous system that base on well-defined neuroanatomical pathways. Acoustical stimuli are transmitted via neural connections to the reticular arousal system (RAS) thus activating the hypothalamus, *i.e.* the center that regulates autonomous excitation first directly via nerval activity and second indirectly via the hypophysis, which controls the hormonal system. These activations then trigger the physiological responses. The reticular arousal system mediates additionally the excitation of the limbic system which in turn evokes emotional alterations. Moreover, neural pathways through the truncus cerebri are the basis for noise-induced reflexes.[10]

Numerous experimental studies were performed in the laboratory to identify and to quantify the great variety of autonomous responses such as accelerated heart rates, increased peripheral resistance, consecutively elevated blood pressure, and elevated releases of stress hormones. These acute responses that occur shortly after noise onset (and shortly after noise offset, on- and off-reactions) are non-specific, *i.e.* they are evoked by various other environmental stimuli and by emotions as well. Their thresholds are found between 60 and 70 dBA during awake and between 50 and 60 dBA during sleep.[11,12] They are primarily normal physiological responses of the organism to its environment, they are clearly determined by the acoustical parameters of noise and increase with sound level and bandwidth. The thresholds and the respective dose-effect curves are modified by personal characteristics and by simultaneously acting environmental agents. The extent of responses vary with age, with the menstrual cycle and with the circadian rhythm where the thresholds are lower during the night than during the day.[12] As these responses do not habituate, they are supposed to contribute eventually to the development of multifactorial chronic diseases, particularly to hypertension and to ischaemic heart diseases. The critical noise load, however, above which these responses become hazardous for health is not yet known.

Some autonomous responses, in particular the release and excretion of stress hormones are usually determined as a cumulative response over the entire exposure period, *e.g.* over a workshift or a night. The disadvantage of this measure is, however, that these responses are also evoked by other stimuli and that it is difficult to quantify the amount that is exclusively related to the impact of noise. This becomes even more difficult if not impossible when stress hormones increase as a secondary effect, *e.g.* when people spend more effort during mental tasks in order to prevent noise-induced impairments. Therefore, this method should be applied preferably in strictly controlled situations.[13]

Concerning the autonomous responses, two trends became apparent in the last decade. First, the number of controlled experiments in the laboratory was reduced in favor of epidemiological studies that are focused to long-term effects on health and second, individual as well as situational vulnerability is increasingly often taken into account (A-Type, self-estimated sensitivity to noise, emotional stress *etc.*).

2.3 Noise-induced Sleep Disturbances

2.3.1 Nature and the function of sleep —Sleep disturbances

Due to its undisputed restorative function, disturbances of sleep are regarded as the most deleterious effects of noise. The respective preconditions are the permanently open auditory channel and the ability of the brain to discriminate between various sounds even while asleep. Sleep is structured by a sequence of 4 to 6 cycles of 90 to 100 minutes each, that are characterized by increasing and decreasing sleep depth and that are terminated by REM-sleep where bursts of rapid eye movements occur.

Sleep disturbances are defined as measurable and/or subjectively experienced deviations from the usual or from the desired sleep behavior. The primary effects that occur during bedtime are for instance prolonged sleep latencies, intermittent and premature awakenings, sleep stage changes, body movements, and autonomous responses. Secondary effects such as decreases of self-estimated sleep quality, mood, and performance are expected after one or several disturbed nights.

2.3.2 Methods for the recording and evaluation of sleep

Only the electrophysiological parameters of sleep (electroencephalogram (EEG), electrooculogram (EOG), electromyogram (EMG)) can reliably indicate whether a person is awake or asleep and provide informations on sleep depth. This most sophisticated and rather costly method is indispensable for laboratory studies. Alternative, but less precise methods are preferred in the field, such as signalled awakenings where the subjects press a button whenever they awake and body movements which are detected by actimeters, that are worn like wrist watches. Autonomous responses are indicated by the alterations of heart rates or by the urinary excretion of stress hormones.

The actual situation, the quantitative and qualitative parameters of sleep are assessed with short questionnaires that are completed just before bedtime and just after getting up. Performance tests that measure working speed and errors (*e.g.* 4-choice tests) are completed every evening and every morning in many studies.

2.3.3 Noise-induced sleep disturbances — state of the art

Noise-induced responses typically start with a K-complex, which is followed by an increase of brain activity, *i.e.* shallower sleep or even awakening. They are accompanied by body movements and autonomous responses. Sleep may become fragmented, the total time awake and/or in shallow sleep increases at the expense of deep sleep and/or of REM sleep. Sleep quality is assessed as worse, mood and performance might be impaired.

The thresholds and the extents of noise-induced sleep disturbances depend on acoustical features, personal characteristics and environmental conditions.

As the brain can recognize the significance of sounds even while asleep, the probability and the extent of sleep disturbances correspond to day-time annoyance which is greatest for aircraft, less for road and the least for rail noise.[14] Sleep disturbances are clearly related to noise levels and number of stimuli. People are less disturbed by rather continuous noises that are produced by vivid road traffic than by intermittent noises which are emitted by air traffic, rail traffic, and low-density road traffic. Sensitizations are possible with time, but most people habituate. Habituation is, however, only limited as indicated by field experiments where long-term residents in noisy areas still wake up more often, have less deep sleep or less REM sleep, assess their sleep quality as worse, perform less in the morning and benefit from sound attenuation (as achieved by ear plugs, sound absorbing windows, tunnels, *etc.*).[15–18]

2.3.4 Personal characteristics

The susceptibility to noise depends on personal factors, personality traits, and on the circadian rhythm. Gender has no influence, but sleep disturbances increase with age and with self-estimated sensitivity to noise. Under quiet conditions night-workers sleep already 1.5 to 2 hours less during the day than during the night; but day-sleep usually takes place under much worse conditions: the noise levels are then 8 to 15 dBA higher and interspersed with meaningful and thus more disturbing noises (children, music *etc.*).

The thresholds of noise-induced responses are inversely related to sleep depth that alters periodically during the night and becomes successively flatter towards the morning.[12,19]

2.3.5 Environmental conditions

Pearsons *et al.*[20] have pooled the data from 21 investigations and have shown that the effects in field studies are much smaller than in the labo-

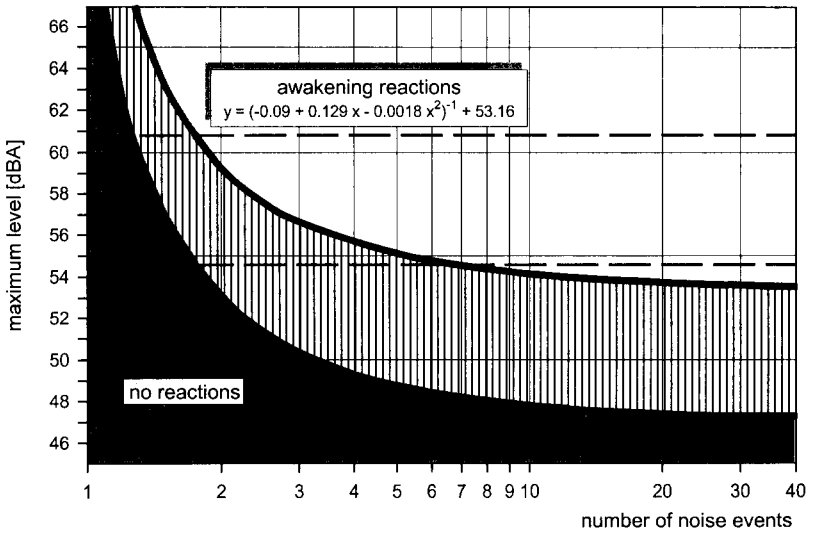

Fig. 2 Curve of equal risks for noise-induced awakenings and sleep stage changes. Relation between maximum admissible maximum levels and the number of noise events per night.

ratory. The possible reasons are in the first place habituation[21] and the simultaneous influence of other acoustic and non-acoustic stimuli that modify or even mask the responses to noise. Moreover, in field studies age, personality traits, physical conditions, vulnerability *etc.* vary in large ranges.

2.3.6 Critical noise loads

Using self-estimated sleep quality and cardiac responses as relevant criteria the critical loads for continuous noises seem to be between equivalent sound levels of 37 and 40 dBA.[22,23] Concerning intermittent noises, where several authors have determined dose-response curves Griefahn[24] provided a curve of equal risks that relates the maximum admissible maximum levels to the number of noise events per night (Fig. 2).

3. SECONDARY EFFECTS

3.1 Performance

Performance might be affected by several mechanisms, directly by arousals and by masking and indirectly by distraction and by noise-induced sleep disturbances.

- Arousals: Optimal performance presupposes a certain arousal level that might vary with the type of a task. Therefore, performance is related with arousal levels and thereby with noise loads by an inversely u-shaped function. Thus, performance is impaired in extremely quiet as well as in loud environments and optimal at moderate sound levels.
- Masking : Tasks that presuppose the perception of acoustical informations or which are at least facilitated by acoustical signals become difficult and even impossible if the informations are masked (*i.e.* in case of disturbed communication).
- Distraction : Various noises, particularly those with high information content (speech, music *etc.*), distract attention, the task-relevant acoustical informations are then only partly or no longer consciously perceived and performance degrades.
- Noise-induced sleep disturbances may degrade the ability to concentrate on a task and thereby impair performance.

The effects of noise on performance reported so far are highly controversial. Impairments, no alterations and even improvements were found. The most likely explanation is that many persons then try to prevent possible noise-induced impairments by more effort. This in turn causes higher physiological costs, such as increased heart rates as well as elevated releases and excretions of stress hormones.[25,26]

The effects on performance depend far-reaching on the task itself. Complicated and demanding tasks, those which presuppose creativity and a great memory capacity and which are executed over a

long time are most likely impaired.[27]

Artificial and continuous noises such as white or pink noise were almost exclusively applied in the very first experimental studies and despite the great variance the effects were related to the noise levels. However, recently performed studies have shown that cumulative noise measures, as for instance the equivalent sound levels are almost irrelevant for usual noises that are characterized by frequent changes in levels and frequencies, where streaming becomes most important. Speech was identified as most bothersome, followed by transportation noise, where air traffic disturbs most and rail traffic the least.[28,29]

Performance is hardly associated with childhood. But children are particularly challenged during language acquisition and they are most vulnerable during that period. In noisy environments children learn to tune out or to ignore auditory stimuli and seem to be more resistant to auditory distraction. These mechanisms are advantageous for irrelevant but disadvantageous for task-relevant sounds. Long-term memory decreases and causes deficits in speech and reading in children living near airports and along major roads.[30,31]

3.2 Annoyance

Annoyance is any feeling of resentment, displeasure, discomfort and irritation when noise intrudes into someone's thoughts and moods or interferes with activities. Noise annoys only when it is not considered to fit with current intentions.

Annoyance is the most significant effect of noise that causes residents who live in the vicinity of airports or along major roads and railway tracks to form pressure groups. Eventually, these responses caused the execution of more than 350 social surveys within the last 4 decades.

Annoyance is undoubtedly related to noise load but the correlations between individual noise load and individual annoyance are relatively low, whereas population based means provided significantly higher correlations.[32] Individual annoyance is determined by a large variety of non-acoustic intervening variables, where behavioral variables such as fear related to the noise source, the conviction that authorities do not properly combat the noise and individual noise sensitivity are most important whereas demographic variables are only of minor significance (*e.g.* age, gender, income, education, home-ownership).[33]

Concerning transportation noises, aircraft noise appears to be most annoying and rail noise the least[14] (Fig. 3). Annoyance is prone to habituation but to sensitization as well where among others the attitude and the context where a noise occurs play a significant role.

Concerning the last decade, two activities deserve to be noticed. First, the attempt to increase the comparability of various studies and second the evaluation of changes of the acoustical environment due to the closing of airports (Munich, Denver), the temporary increase of traffic density (Atlanta, Olympic Games), the extension of existing (Sydney) or the opening of new airports (Munich, Denver), the establishment of sound barriers and tunnels and

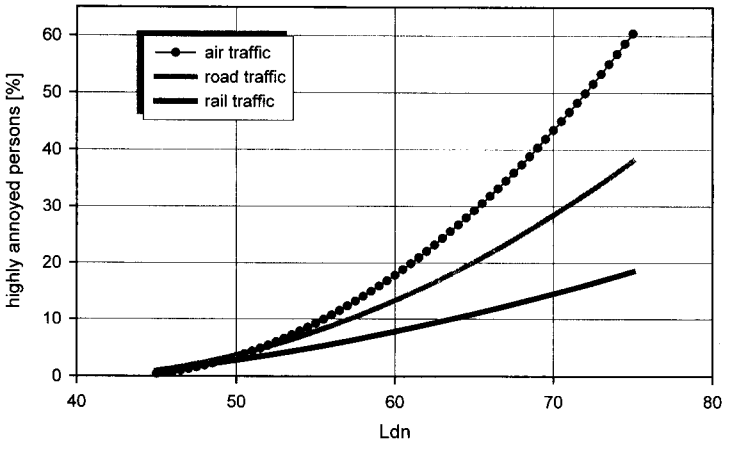

Fig. 3 Percentage of residents highly annoyed by different transportation noises as related to the L_{dn}.[14]

the opening of new roads or rail tracks.[18,34,35]

4. LONG-TERM EFFECTS ON HEALTH

Frequently evoked primary and secondary responses that are described in sections 2 and 3 are usually tolerated for a while and the people concerned develop a great variety of coping strategies. In the long run, however, in case of chronic noise exposure these responses are supposed to contribute to the genesis and manifestation of multifactorial chronic diseases. This well-founded hypothesis was examined with many epidemiological studies, that concerned particularly hypertension, ischaemic heart diseases, and cardiovascular risks such as elevated levels of cholesterol and triglycerides, of epinephrine, norepinephrine and cortisol; a few studies dealt with the immune system, with reproduction, with sick leave from work and with accidents.

The crucial significance of these hypothesized relations caused several authors and committees to review as many studies as possible and to pool the results for summarizing analyses while concerning different aspects. The first analysis revealed highly contradictory results which led to the assumption that the pathogenic impact of noise presupposes a particular individual or situational vulnerability. It was hypothesized that the primary physiological responses are decisive for the long-term effects and that noises with a high emotional content evoke stronger responses and contribute more to health effects rather than neutral noises.[36] After the respective studies were then grouped according to the possible emotional content of noise, into those which dealt with occupational noises where the emotional strain usually decreases and even diminishes soon and into those which dealt with transportation noises that affect people during their leisure time and cause considerable emotional responses the results of the respective analysis supported the suspicion that the emotional content of a noise is decisive for the long-term effects.

This assumption was resumed for further analyses of epidemiological studies.[2,3,10,37–41] They revealed that the studies on occupational exposures are still contradictory. The reports on environmental noise, in particular on transportation noise indicate that day-time outdoor levels of considerably more than 80 dBA are associated with a higher risk for hypertension and very high long-term exposures of more than 90 dBA with other cardiovascular findings (*e.g.* heartbeat irregularities, increased heart rate, ECG abnormalities, decreased blood supply to the myocardium).[2,10] Other reviewers determined the respective thresholds at at least 70 dBA for hypertension and between 65 and 70 dBA for ischaemic heart diseases.[37] Some authors and committees[2,10] consider the evidence for causal relationships as sufficient whereas Job[42] in agreement with Thompson[41] stated that 'Rigorously controlled studies which eliminate the numerous confounding factors or at least a number of them, are rare.' and Porter *et al.*[3,5] concluded that 'research has not definitely' proved 'any causal linkage between environmental noise and long term adverse health effects' but that 'it remains inherently plausible that excessive noise might contribute to long term adverse health effects' and 'that it is not possible at this time to establish health effect based assessment methods'.

Stress might have an adverse effect on the immune system, however, studies on this topic are sparse not allowing to draw definite conclusions. The same has to be stated for the effects on the unborn child, whether the pregnant women were exposed to environmental or to occupational noise.[10]

Another founded hypothesis, *i.e.* the development of psychiatric disorders —at least in particularly susceptible persons— was proved several times and psychiatric hospital admissions were indeed somewhat higher in the vicinity of large airports but this needs to be confirmed by well designed studies.[39]

Apart from hypertension, ischaemic heart diseases and possible psychiatric symptoms it is assumed that people daily exposed to noise are more susceptible for other diseases and symptoms such as common colds, and digestive problems. The respective investigations are, however, inconclusive as they were again poorly designed and did not take into account possible confounders.[10,42]

5. FUTURE RESEARCH AND RECOMMENDATIONS

Numerous experiments and field studies on the effects of noise were performed within the last 4 decades. They were focused on the detection and to the description of the various effects of noise, to the determination of dose-response relations and to the influence of exogenic and endogenic factors. They led to a profound insight into the mechanisms

of noise processing and to the hypothesis that noise in the long run contributes to the development of health disorders. Yet, the quantitative aspects are not well defined, particularly in view of limits, above which noise becomes intolerable with respect to performance, to sleep, to communication and particularly to health. A few studies suggested such limits which are, however, due to the small database only tentative or applicable for a very few situations.

Despite extensive research in the past much remains to be done. Some main topics are discussed below.

5.1 Noise-induced Responses and Health Impairments

Whatever the reason may be, it is generally believed that chronic noise exposure contributes to the genesis and manifestation of several multifactorial chronic diseases, of chronic annoyance, and permanent behavioral alterations but the assumed causal linkages between environmental noise, primary and secondary effects on the one hand and the hypothesized final outcomes on the other hand remain to be determined.[2,3,5,39,43] It is therefore still uncertain which of the great number of various noise effects are most appropriate for the description and quantification of noise effects. Regarding for instance noise-induced sleep disturbances, research was mainly restricted to the period between sleep onset and sleep offset where the time for falling asleep, premature awakenings, performance the next morning and other possible after-effects on work performance (*i.e.* productivity), accident risk and social life were not or insufficiently studied.

5.2 Field Observations and Laboratory Studies

Apart from social surveys on community reactions, the effects of noise were at first almost exclusively studied in the laboratory. Extensive technical and methodological developments allowed more and more the execution of field studies, *i.e.* the observation of man in his or her usual environment, at home or at the workplace. However, the most striking reports of the last decade concerned the discrepancies between the effects observed in the laboratory and in the field. The latter are as a rule much smaller and even negligible, probably due to habituation, to frequent changes of the acoustical situation, to the simultaneous influence of various environmental factors and to the great variance concerning the actual situation, including mood, activity, health state, attitude *etc.*

These discrepancies must be elucidated and some aspects are considered in the following sections.

(Remark : Field experiments assume an intermediate position. These are studies, where sound pressure levels were altered by the variation of window positions, the use of earplugs, the installation of sound insulations. The results obtained are —as expected— between those registered in the laboratory and the field.)

5.3 The Assessment of the Acoustical Situation

A serious shortcoming of most field studies is that noise load is mainly estimated by measures at the source, or at a representative point of a residential area or of a working hall whereas individual noise immission is precisely quantified in the laboratory.

The majority of experiments concerned artificial sounds where the systematic variation of levels, frequencies, and bandwidth revealed dose-effect relationships that decrease or even diminish in the field where man is exposed to real sounds such as transportation noise or speech. The information content and the streaming, *i.e.* the temporal changes in levels and frequencies are most decisive for the processing of these noises, meaning that the equivalent sound pressure levels are not adequate for the prediction of these effects.

Another disadvantage is, that the assessment of noisy environments refers almost exclusively to the dominant noise source. But, as man reacts to other simultaneously acting noises as well, it is essential to evaluate the acoustical situation as a whole, and to include noises from other sources as well. This is particularly reasonable for situations where various noises are related to each other, *e.g.* at airports where the increase of air traffic is necessarily accompanied by an increase of road and rail traffic.

The development of predictive models must be pursued, where it might be reasonable to create far-reaching realistic settings in the laboratory for the development of models which then must be proved and perhaps adapted to field situations. Some researchers and committees[10,39] stress particularly to the lack of research into the cumulative effects of various noises that occur successively over the 24 hours day (*e.g.* occupational and environmental noise).

5.4 Temporal Aspects

The time of day is significant for annoyance, performance, autonomous responses and sleep and this is related to both, the individual circadian rhythm and the periodical diurnal alterations of the environment. The time which people spend at home is concerned as most susceptible with respect to annoyance which then might affect other functions, *e.g.* the following sleep period. The quality and quantity of sleep depend per se on timing and are particularly susceptible against noise whenever people sleep at unusual times. Night-time and day-time are legally defined in most countries but many persons sleep at least partly outside these hours.[13] This becomes more frequent with the ongoing flexibility of working hours. Therefore, suitable concepts for protection, in particular for those who perform shift work must be developed.

People want to relax and to communicate during their leisure time.[44] However, whether and to what degrees noise-induced disturbances of communication and of other activities during the evening hours (shoulder hours) impair the consecutive sleep period or increase the susceptibility against nocturnal noise is not yet known.

5.5 Individual Vulnerability

Experimental research is almost exclusively performed with young and healthy persons. This is justified as long as the identification of various responses and the respective mechanisms are the center of attention. However, exposure limits deduced from those studies are only tentative. Their establishment improves the situation for everybody but does not prevent vulnerable persons from the deleterious effects of noise. But up to now, vulnerable people, with hypertension, with a respective family history, blind and deaf persons were only occasionally studied. Concerning personality traits, other than self-estimated sensitivity to noise were hardly considered though other personality traits, in particular neuroticism and anxiety as well as illness are supposed to determine the susceptibility to noise.

Children are most susceptible during the period of language acquisition and directed studies revealed indeed a retarded development of speech and reading of children living in noisy areas. Whether childhood is also associated with a particular vulnerability of the autonomous nervous system was proved in a few studies on blood pressure and on the release of stress hormones which, however, need to be replicated.

5.6 Habituation

Another reason for the discrepancy between field and laboratory studies is that experimental exposures take place only once or a very few times whereas exposures at home or at the workplace are daily repeated. Where the autonomous responses do not habituate, other responses, such as sleep disturbances and annoyance decrease during time. But the quantitative aspects of habituation are not yet well understood, in particular as this interferes with the effects of other simultaneously acting influences. This is certainly a major problem for future studies as the extent of habituation is decisive for the prediction of long-term effects on health.

5.7 Combined Stress

The real situation at the workplace and in the non-occupational environment is determined by the simultaneous influence of different agents that modify the responses of the organism to noise. Research on combined agents was started with great enthusiasm, but due to methodological shortcomings and the application of non-adequate statistical procedures, many of these studies were done in vain. So, research in this area is still in its infancy and needs to be intensified in the future.

5.8 Accumulation of Data from Different Studies

Up to now, several thousand experiments were performed in the laboratory and several thousand persons living or working in noisy environments were studied. This led to the attempt to pool the data from different studies for summarizing analysis concerning sleep disturbances, community reactions, and health effects. But due to considerably varying concepts, to different methodological procedures and shortcomings only a few studies could be used for accumulation and led accordingly to only tentative results. The co-operation of different working groups is therefore urgently recommended.

An important step was done by researchers working on annoyance (International Noise Team 6 : Community Responses to Noise of the International Commission on Biological Effects of Noise). Their respective concept does not presuppose an actual co-operation. Instead, researchers are requested to

adopt the philosophy that their own individual studies are primarily essential elements in the achievement of a common goal. Guidelines were formulated for the reporting of social surveys and 2 shared annoyance questions were elaborated for inclusion into future studies. The 2 questions base on an appropriate study with overall 738 participants living at 22 sites in 10 countries with 8 languages. These questions are as follows:

- Question 1: Thinking about the last (year, months) when you are here at home, how much does noise from (source) bother, disturb or annoy you (very —moderately—slightly—not at all)?
- Question 2: ...On a zero to ten scale what number from zero to ten best shows how much you are bothered or annoyed by (source) noise?

These 2 questions increase the comparability of different studies even if executed in different cultures and with different languages and allow the accumulation of the data for common analyses. It is urgently recommended to develop similar guidelines and common elements also for epidemiological studies on health effects, for studies on noise-induced sleep disturbances, on performance and communication. The shared elements for future studies might consist of a common protocol, a standardized questionnaire, the application of a 'reference' noise, *etc.*

5.9 Preventive Measures and Evaluation Studies

The present knowledge is sufficient to claim urgently for preventive measures that must be established yet. The effects of attenuation (deviation of traffic, construction of tunnels, double glazing, *etc.*) must be evaluated by appropriately designed studies.

REFERENCES

1) European Commission, "Green paper on future noise policy," COM 540 Final (1997).
2) HCN —Health Council of the Netherlands, "Committee on the Health Impact of Large Airports. Public health impact of large airports," The Hague: Health Council of the Netherlands, Publication no 1999/14E (1999).
3) N. D. Porter, I. H. Flindell, and B. F. Berry, "Health effect-based noise assessment methods: A review and feasibility study," NPL Report CMAM 16 (1998).
4) WHO World Health Organization, *Yearbook of International Organizations* (1968-69).
5) N. D. Porter, A. D. Kershaw, and J. B. Ollerhead, "Adverse effects of night-time aircraft noise," R & D Report 9964, Department of Operational Research and Analysis, National Air Traffic Services Ltd. (2000).
6) H. Lazarus, "Noise and communication: Present state," in *Noise Effects '98*, N. Carter and R.F.S. Job, Eds. (Noise Effects '98 Pty Ltd., Sydney, 1998), pp. 157-162.
7) B. M. Brooks, T. J. DuBois, D. Lubman, M. T. Nixon, K. S. Pearsons, M. Schaffer, S. D. Soli, and L. C. Sutherland, "Need and issues for American Standards and guidelines for classroom acoustics," in *Noise Effects '98*, N. Carter and R.F.S. Job, Eds. (Noise Effects '98 Pty Ltd., Sydney, 1998), pp. 191-194.
8) R. McKinley and C. Nixon, "Enhance communications in noise for moderately hearing impaired with customized ANR," in *Noise Effects '98*, N. Carter and R.F.S. Job, Eds. (Noise Effects '98 Pty Ltd., Sydney, 1998), pp. 174-180.
9) J. Edworthy and E. Hellier, "Auditory warnings in noisy environments," Noise & Health **6**, 27-39 (2000).
10) W. Passchier-Vermeer, "Noise and health," The Hague: Health Council of the Netherlands, Publication no A93/02E, (1993).
11) B. Griefahn, "Cardiac responses caused by shots of tanks during sleep," J. Sound Vib. **128**, 109-119 (1989).
12) A. Muzet, J. Ehrhart, R. Eschenlauer, and J. P. Lienhard, "Habituation and age differences of cardiovascular responses to noise during sleep," in *Sleep 1980*, Koella, Ed. (Karger, Basel, 1981), pp. 212-215.
13) B. Griefahn, A. Schuemer-Kohrs, R. Schuemer, U. Moehler, and P. Mehnert, "Physiological, subjective, and behavioural responses to noise from rail and road traffic," Noise & Health (in press).
14) H. M. E. Miedema, "Revised DNL-annoyance curves for transportation noise," in *Noise Effects '98*, N. Carter and R.F.S. Job, Eds. (Noise Effects '98 Pty Ltd., Sydney, 1998), pp. 491-496.
15) J. L. Eberhardt and K. R. Akselsson, "The disturbance by road traffic noise of the sleep of young male adults as recorded in the home," J. Sound Vib. **114**, 417-434 (1987).
16) B. Griefahn B and E. Gros, "Noise and sleep at home, a field study on primary and after-effects," J. Sound Vib. **105**, 373-383 (1986).
17) A. A. Jurriëns, B. Griefahn, A. Kumar, M. Vallet, and R. T. Wilkinson, "An essay in European research collaboration: common resuls from the project on traffic noise and sleep in the home," in *Noise as a Public Health Problem*, G. Rossi, Ed. (Edizioni Tecniche a cura del Centro Ricerche e Studi Amplifon, Milano, 1983), pp. 929-937.
18) E. Öhrström, A. Agge, and M. Björkman, "Sleep disturbances before and after reduction in road traffic noise," in *Noise Effects '98*, N. Carter and R.F.S. Job, Eds. (Noise Effects '98 Pty Ltd., Sydney, 1998), pp.

451-454.
19) B. Griefahn, *Schlafverhalten und Geräusche* (Enke, Stuttgart, 1985).
20) K. Pearsons, D. S. Barber, B. Tabachnik, and S. Fidell, "Predicting noise-induced sleep disturbance," J. Acoust. Soc. Am. **97**, 331-338 (1995).
21) L. S. Finegold, "Current status of sleep disturbance research and development of a criterion for aircraft noise exposure," 126th Meeting of the Acoustical Society of America Denver, Colorado, USA (1993).
22) B. Griefahn, "A critical load for nocturnal high density road traffic noise," Am. J. Ind. Med. **9**, 261-269 (1986).
23) M. Vallet, J. M. Gagneux, V. Blanchet, B. Favre, and G. Labiale, "Long term sleep disturbance due to traffic noise," J. Sound Vib. **90**, 173-191 (1983).
24) B. Griefahn, "Noise control during the night," Acoust. Aust. **20**, 43-47 (1992).
25) A. P. Smith and D. J. Nutt, "Noradrenaline and lapses of attention," Nature, 291-308 (1996).
26) R. J. Tafalla and G.W. Evans, "Noise, physiology and human performance: The potential role of effort," J. Occup. Health Psychol. **2**, 148-155 (1997).
27) I. Enmarker, E. Boman, and S. Hygge, "The effects of noise on memory," in *Noise Effects '98*, N. Carter and R.F.S. Job, Eds. (Noise Effects '98 Pty Ltd., Sydney, 1998), pp. 353-356.
28) R. Boyle and V. Coltheart, "Effects of irrelevant sounds on phonological coding in reading comprehension and short-term memory," Q. J. Exp. Psychol. **49**, 398-416 (1996).
29) J. Hellbrück, S. Kuwano, and S. Namba, "Irrelevant background speech and human performance: Is there long-term habituation ?," J. Acoust. Soc. Jpn. (E) **17**, 239-247 (1995).
30) G. Evans and L. Maxell, "Chronic noise exposure and reding deficits," Environ. Behav. **29**, 638-656 (1997).
31) S. Hygge, D.M. Jones, and A.P. Smith, "Recent developments in noise and performance," in *Noise Effects '98*, N. Carter and R.F.S. Job, Eds. (Noise Effects '98 Pty Ltd., Sydney, 1998), pp. 321-228.
32) R. F. S. Job, "Community responses to noise: A review of factors influencing the relationship between noise exposures and reactions," J. Acoust. Soc. Am. **83**, 991-1001 (1988).
33) J. M. Fields, "A review of an updated synthesis of noise/annoyance relationships," NASA Report 194950, Georgia Institute of Technology, Atlanta, GA (1990).
34) G. W. Evans, M. Bullinger, and S. Hygge, "Chronic noise exposure and physiological response: A prospective study of children living under environmental stress," Psychol. Sci. **9**, 75-77 (1998).
35) S. Fidell, R. Howe, B. Tabachnik, K. Pearsons, and M. Sneddon, "Noise-induced sleep disturbance near two civil airports," Contract NAS1-20101, NASA Langley Research Center (1995).
36) B. Griefahn, "Lärmbelastung-Lärmwirkung," Verh. Dtsch. Ges. Arbeitsmed. **29**, 83-92 (1990).
37) W. Babisch, "Epidemiological studies of cardiovascular effects of traffic noise," in *Noise Effects '98*, N. Carter and R.F.S. Job, Eds. (Noise Effects '98 Pty Ltd., Sydney, 1998), pp. 221-229.
38) W. Babisch, "Epidemiological studies of the cardiovascular effects of occupational noise —A critical appraisal," Noise & Health **1**, 24-35 (1998).
39) HCN —Health Council of the Netherlands, "Committee on noise and health. Noise and health," The Hague: Health Council of the Netherlands, Publication no 1994/15E (1994).
40) S. Morrell, R. Taylor, and D. Lyle, "A review of health effects of aircraft noise," Aust. N. Z. J. Public Health **21**, 221-236 (1997).
41) S. Thompson, "Non-auditory health effects of noise: updated review," in Noise Control —The Next 25 Years, Proceedings of the inter noise '96, Institute of Acoustics, St. Albans, Ed. (Liverpool, UK, 1996), pp. 2177-2182.
42) R. F. S. Job, "The influence of subjective reactions to noise on health effects of the noise," Environ. Int. **22**, 93-104 (1996).
43) B. F. Berry and M. Jiggins, "An inventory of UK research on noise and health from 1994 to 1999," NPL Report CMAM 40 (1999).
44) J. M. Fields, "The relative effect of noise at different times of day. An analysis of existing survey data," Langley Research Center —Contract NAS1-16978. NASA Contractor Report 3965 (1986).

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