The permanently open auditory channel and the ability of the brain to process incoming acoustical stimuli even while asleep and to respond adequately is the essential precondition for noise-induced sleep disturbances which are regarded as the most deleterious effects of noise. In the past, research was mainly focused on the detection and description of the various effects of noise, on the influence of personal and environmental factors, on the determination of dose-response relations and the definition of critical noise loads, above which noise becomes intolerable. These limits are, however, as yet only tentative or applicable for a very few situations and need to be verified or revised.

The present paper is focused on the priorities for future research. These are in particular 1) the causal linkage between environmental noise, primary and secondary effects on the one hand and the hypothesized contribution to multifactorial chronic diseases, to chronic annoyance, and to permanent behavioural alterations on the other hand, 2) the identification of the causes for the great discrepancies between the small effects determined in the field and the large responses recorded in the laboratory, 3) temporal aspects such as sleep at unusual times (day sleep after nightshifts), definition of night-time and day-time, 4) the significance of the shoulder hours for subsequent sleep, 5) the individual vulnerability, 6) the accumulation of data from different studies.

Keywords: noise-induced sleep disturbances, research priorities

The nature and the function of sleep – Sleep disturbances
Due to its undisputed restorative function, sleep disturbances are regarded as the most deleterious effects of noise.

The methods for the recording and evaluation of sleep are many-fold. The polysomnogram is the only measure that reliably indicates whether a person is awake or asleep and that provides information on sleep depth. Less sophisticated measures are used in the field, such as signalled awakenings, body movements, or the urinary excretion of stress hormones. Self-estimated sleep quality, bedtimes and rising times, and coping strategies are determined with questionnaires and performance with suitable tests just before bedtime and after getting up.

Studies performed in the past were focused on the detection and description of the various effects of noise, on the determination of dose-response relations and on the influence of exogenic and endogenic factors. They led to a profound insight into the mechanisms of noise processing.

The acute primary effects start with a K-complex, that is followed by an increased brain activity and accompanied by body movements and autonomous responses. They accumulate over the whole sleep period and increase the total time in shallow sleep and/or the time awake at the expense of deep sleep and/or of REM sleep. Secondary effects after noisy nights are impaired self-estimated sleep quality, mood, and performance.

The essential preconditions of noise-induced sleep disturbances are the permanently open auditory channel and the ability of the brain to discriminate between various sounds even while asleep and to respond adequately. The content of information depends, however, not only on the acoustical parameters of noise but mainly on the...
experience of a person with that particular noise. Its overwhelming significance causes the large inter- and intraindividual variance and explains that low-intensity noises might disturb more than louder noises. The content of information can alter with time thus providing the basic mechanism for sensitization and habituation. Habituation, however, remains incomplete as demonstrated in the field where residents in noisy areas woke up less often, spent more time in deep sleep or in REM sleep, assessed their sleep quality as better, and performed better after sound attenuation (Eberhardt and Akselsson, 1987; Griefahn and Gros, 1986; Jurriëns et al., 1983; Öhrström et al., 1998; Öhrström, 2001).

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

Acoustical features: Sleep disturbances are clearly related to noise levels, to the number of stimuli, to frequency spectra etc and people are less disturbed by continuous than by intermittent noises (Eberhardt and Akselsson, 1987; Öhrström and Ryländer, 1982).

Personal characteristics: The susceptibility to noise depends on personal factors, personality traits, and on the diurnal type. Gender has no influence, but sleep disturbances increase with age and with self-estimated sensitivity to noise (Muzet et al., 1985; Muzet et al., 1980; Öhrström and Björkman, 1988).

Environmental conditions: It has been shown that the effects in the field are much smaller than in the lab. The reasons are mainly habituation and the simultaneous influence of other acoustic and non-acoustic stimuli that modify or even mask the responses to noise (Fidell et al., 1995; Pearsons et al., 1995; Porter et al., 2000).

Critical noise loads: The limits, above which noise becomes intolerable are as yet only tentative or applicable for a very few situations and need to be verified or revised. Based on 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 (Griefahn, 1986; Vallet et al., 1983). Concerning intermittent noises, a curve of equal risks was provided that relates the admissible maximum levels to the number of noise events per night (Griefahn, 1992).

Priorities for future research

Causal linkage to health impairments: The effects of noise on sleep are non-specific. It is therefore difficult to determine causal relationships, the more the longer the time lag between the onset of noise exposure and the manifestation of an effect in question. Causal relations are only obvious for acute primary effects.

The crucial question concerning the causal linkage between environmental noise, primary and secondary effects on the one hand and the hypothesized contribution to multifactorial chronic diseases, to chronic annoyance, and to permanent behavioural alterations on the other hand remains to be answered. Only the solution of this problem can clarify the significance of the various primary and secondary effects which are as yet insufficiently studied, e.g. the time for falling asleep, premature awakenings, performance the next day (i.e. productivity), accident risk, and social life (Porter et al., 2000; Berry and Jiggins, 1999; HCN – Health Council of the Netherlands, 1994).

Adopting, however, the WHO definition of health as ‘a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity’, awakenings that determine subjectively assessed sleep quality and mood are clearly classified as health effects (WHO World Health Organization, 1968-1969).

Field versus laboratory studies: The effects of noise were at first almost exclusively studied in the lab. Extensive technical developments allowed more and more the observation of people in their usual environment. But the most striking reports of the last decade concerned the discrepancies between the effects observed in the lab and in the field (Pearsons et al., 1995). The latter are as a rule much smaller, probably due to
habituation, and to masking by the simultaneous influence of various environmental factors and to the great variance concerning the actual situation (Pearsons et al., 1995; Porter et al., 1998, Porter et al., 2000).

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 whereas individual noise immission is precisely quantified in the lab. In addition, the assessment of noise load refers almost exclusively to the dominant source. But people react to the acoustical situation as a whole, and this requires the inclusion of noises from other sources as well. This is particularly necessary for situations where various noises are related to each other, e.g. at airports where the increase of air traffic is accompanied by an increase of road and rail traffic.

Habituation: Experimental exposures take place only once or a very few times whereas exposures at home are daily repeated. Though the autonomous responses do not habituate, awakenings and sleep stage changes decrease during time (Griefahn et al., 2000). But the quantitative aspects of habituation are not yet well understood. This is certainly a major problem for future studies as the extent of habituation is certainly decisive for the development of long-term effects on health (Porter et al., 2000; Griefahn et al., 2000; Finegold, 1993).

Temporal aspects: Due to diurnal oscillations of physiological functions and environmental conditions, the quality and quantity of sleep as well as noise-susceptibility alter accordingly. This becomes evident when people are forced to sleep at unusual times. In comparable acoustical conditions, nightworkers sleep significantly less during the day than during the night; but daytime conditions are usually worse with higher noise levels and with interspersed meaningful and more disturbing noises.

Night-time and day-time are legally defined in most countries but many persons sleep at least partly outside these hours (Griefahn et al., 2000; Passchier-Vermeer and Passchier (2000) and this becomes more frequent with the ongoing flexibility of working hours. Therefore, suitable concepts for protection must be developed.

People want to relax and to communicate during leisure time. But whether and to what extent noise-induced disturbances of communication and of other activities during this time affect the consecutive sleep period or the susceptibility against noise is not yet known.

Individual vulnerability: Experimental research was 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 centre of attention. But exposure limits deduced from those studies are only tentative. Their establishment improves the situation for everybody but does not fully protect vulnerable persons, who were as yet only occasionally studied. Concerning personality traits, other than self-estimated sensitivity to noise were hardly considered though e.g. neuroticism and anxiety are supposed to be significant (Muzet et al., 1985 ; Muzet et al., 1980; Öhrström and Björkman, 1988).

Accumulation of data from different studies: Up to now, many experiments were performed in the lab and several hundred persons were studied in their usual environment at home. But due to considerably varying concepts and to different methodological procedures, only a few studies can be used for accumulation. It is therefore essential that researchers understand their individual studies primarily as essential elements in the achievement of a common goal and include common elements in their future studies, e.g. a common protocol, a standardized questionnaire, the application of a ‘reference’ noise, etc (Griefahn, 2000).

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