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Guidance on potential health effects of noise

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The Expert Panel on Noise (EPoN) of the European Environmental Agency (EEA) is currently preparing a guidance document on potential health effects of noise. The goal of this document is to collect and distribute knowledge about the health effects of noise. The emphasis is to provide end-users practical and validated tools to calculate health impacts of noise in all kind of strategic studies like the action plans or environmental impact statements. The noise mapping data according to the European Noise Directive (END) can be used for quantitative risk assessment and decision making in public health policies, in principle. However, there are limitations due to the incompleteness of the exposure data and the restriction to major agglomerations after the first round of END noise assessment. The basis of the fact sheet is a number of recent reviews by well known institutions like WHO, National Health and Environment departments and professional organisations. The focus is clearly on established exposure-response curves for certain endpoints that can be used to estimate the number of affected people in communities and countries as a whole. Practical examples are shown how noise exposure data and health data can be linked for risk assessment, the calculation of public health indicators, such as DALYs (disability adjusted life years), and cost-benefit analyses. Finally, recommendations for quality targets will be made.

1 Introduction

The Expert Panel on Noise (EPoN) was established in 2009 with the aim of supporting the European Environment Agency (EEA) and other EU institutions with the implementation and development of an effective noise policy for Europe. The group will built upon tasks delivered by previous working groups, particularly regarding Directive 2002/49/EC relating to the assessment and management of environmental noise. One of seven priority tasks is to assist with the development of the European Noise Database and specifically advise on the linkages between population exposure and potential health effects. On behalf of the whole group the authors of this article are currently preparing a guidance document (initially named fact sheet) on potential health effects of noise. The document will be finalised in the near future. Particular emphasis is made in the document on reasonably well established exposure-response curves that can be used for a quantitative risk assessment. The present paper gives an overview about the health endpoints and indicators that will be considered. Noise mapping data from all over Europe will be increasingly used for health impact assessment, action planning and as a source of exposure assessment in noise effects studies.

2 Health endpoints and intermediary effects

Table 1 refers to health endpoints that have been heavily studied in noise effects' research. The broad WHO definition is used for the definition of health, including states of psychological and social well-being. Some health endpoints may also be qualified as intermediary effects. These can be used to assess special situations where the uncertainty in relation to the endpoints in terms of health and well-being is large (e. g noise sources for which exposure-response relationships have not been established). The table lists the major outcomes that can be measured, the dimension of health or quality of life that is concerned, the acoustic indicator that has been used primarily for the assessment of an exposure-response relationship, the estimated threshold of effect based on the exposure-response relationship, and the latency or time domain for the development of the (adverse) noise effect.

Table 1: Effects of noise on health with sufficient evidence

Effect	Dimension	Acoustic Indicator *	Threshold **	Time domain
Annoyance, Disturbance	Psychosocial, Quality of life	L_{den}	42	Chronic
Learning, Memory	Performance	L_{den}	50	Acute, Chronic
Self-reported sleep disturbance	Quality of life, Somatic health	L_{night}	42	Chronic
Sleep (electro-physiological)	Arousal, Motility, Sleep quality	$L_{max, indoors}$	32	Acute, Chronic
Reported awakening	Sleep quality	$SEL_{indoors}$	53	Acute
Stress hormones	Stress indicator	L_{max} L_{eq}	NA	Acute, Chronic
Hypertension	Physiology, Somatic health	L_{den}	50	Chronic
Ischaemic heart diseases	Clinical Health	L_{den}	60	Chronic
Reported Health	Wellbeing, Clinical health	L_{den}	50	Chronic

* L_{den} and L_{night} are defined as outside exposure levels, L_{max} is not defined
** Level above which effects start to occur or start to rise above background

3 Exposure-response curves

3.1 Noise annoyance

Noise annoyance is the most heavily investigated endpoint that has been studied. Although the quantity of highly annoyed as a cut-off point (72% of scale length) is widely used, relations for annoyed (50%) and average score are available. The so-called 'Miedema curves' have been adopted as an European standard for the prediction of the percentages of 'highly annoyed', 'annoyed' and (at least) 'little annoyed' subjects in populations. Exposure-response relations for the transport noises road, rail and air traffic were laid down in the EU-Position Paper (2002) [1]. For transport noises the thresholds are taken to be the same (42 Lden), but this is definitely not true for special noises like wind-turbines and shunting yards. Annoyance is source dependant. Exposure-response relations for other noises (e.g.: industry) are not available on EU-level, but useful data is available from other sources [2-3].

The relations provided by the EU-position paper on exposure-response relations for road traffic noise have largely been confirmed by later studies. Use of these relations is therefore recommended. The EU-position paper relations for railway noise are valid for most types of railways. Studies in Japan and Korea (some on high speed lines) sometimes show higher annoyance, but a systematic review is missing. The EU-relations for aircraft noise have been criticized because in series of recent surveys a decrease of the level needed to cause 25% highly annoyed over time was found [4]. Subsequent analyses seemed to confirm this, but couldn’t find a single explanation [5]. A recent multi-centred study (HYENA) showed that this change of annoyance was only found for aircraft noise but not for road traffic noise [6]. In a recent report an estimate was made of the average of aircraft noise studies carried out after 1990. These were all

European studies (Switzerland, Germany, Netherlands) and so may give a better impression than the pre-1990 studies which are mainly from USA and Australia [7]

3.2 Self-reported sleep disturbance

Self-reported sleep disturbance is measured like annoyance by questionnaire. Exposure-response relationships for road traffic, railway and aircraft noise are given in the EU-position paper (2004) [8]. In chapter 3.1 it was indicated that aircraft noise was found to be more annoying in studies after 1990. This is also true - though to a lesser extent - for self reported sleep disturbance [7]. Experimental and sociological evidence shows that people awake between 1 and 2 time per night. These awakenings may be defined as reported, conscious, remembered or confirmed awakenings depending on the setting. Although the function of sleep is still somewhat obscure, sleep deprivation is definitely a condition that deeply afflicts health. Animal experiments show that sleep deprived animals have a reduced life expectancy, and sleep deprived humans typically show dramatic function loss after a few days. Any increase in awakenings is therefore to be taken serious. As sleep is so important, the organism tends to suppress awakenings. This is the reason why the occurrence even at high noise levels remains low.

3.3 Physiological changes during sleep

The WHO-Night Noise Guidelines (2009) [9] discusses in great detail the relations between, noise, sleep quality and health. Although recommendations are expressed in terms of Lnight (the night time noise indicator from the END), the report describes also a number of exposure-response relationships for instantaneous reactions. The changes in brainwave pattern are measurable by EEG-machines, and are categorized in sleep stage changes and arousals, or EEG-awakenings (changes to wake or to sleep-stage S1 within 90 seconds that last for at least 15 seconds after a noise event). Although not considered as health effect per se, it is considered a significant early warning signal. As shown in the DLR-studies into aircraft noise the body starts to react to intruding sounds at very low sound level [10]. At maximum sound levels (L_{max}) as measured inside the bedroom exceeding 33 dB(A) an increase is found in the probability of a noise induced EEG awakening in additional to the 24 awakenings that usually occur even during undisturbed nights.

The exposure-response relationship on the single event level was used to predict the expected degree of sleep fragmentation depending on L_{night} (outside the bedroom), using data from the DLR-field study [10] and simulation techniques to estimate the average number of EEG awakenings additionally induced by aircraft noise per year based on empirical exposure data around Frankfurt, including window opening habits ([11]. The risk of additional EEG-awakenings increases from outdoor noise levels (L_{night}) of 40 dB(A) onwards. The WHO interim target of $L_{night,outdoors}$ 55dB(A) corresponds approximately with one additional EEG-awakening per night throughout the whole year.

3.4 Cardiovascular effects

Ischaemic heart disease (including myocardial infarction) and hypertension (high blood pressure) have been much investigated with respect to noise. The hypothesis that chronic noise affects cardiovascular health is due to the following facts (biological plausibility): (1) Laboratory studies on humans have shown that exposure to acute noise affects the sympathetic and endocrine system, resulting in unspecific physiological responses (e. g. heart rate, blood pressure, vasoconstriction, stress hormones, ECG). (2) Noise-induced instantaneous autonomic responses do not only occur in waking hours but also in sleeping subjects even when no EEG awakening is present. They do not fully adapt on a long-term basis although a clear subjective habituation occurs after a few nights. (3) Animal studies have shown that long-term exposure to high noise level noise yields to manifest health disorders, including high blood pressure and 'aging of the heart'. (4) Although effects tend to be diluted in occupational studies due to the "healthy worker effect", epidemiological studies carried out in the occupational field have shown that employees working in high noise environments are at a higher risk of high blood pressure and myocardial infarction. A biological pathway has been suggested that explains the hypothetical pathway from noise to cardiovascular diseases [12]: sound/noise exposure + noise annoyance => activation of the endocrine and autonomous nervous system => increase in biological risk factors due to imbalance of homeostasis (physiological equilibrium) => cardiovascular disease. During sleep, the autonomous responses responds to single noise events, including changes in blood pressure and heart rate, even in subjects who were subjectively not sleep disturbed [13]. Meta analyses were carried out to assess the evidence of the association between environmental noise and cardiovascular health outcomes [14-15], and to quantify the risk of high blood pressure and ischaemic heart diseases (including myocardial infarction) on the basis of pooled exposure-response curves for adults and children [16-18].

3.5 Cognitive impairment

A number of laboratory studies indicate that noise may influence learning and performance, but the relation is complex, as people usually try to keep the performance up. This kind of research was primarily carried out in schoolchildren. The RANCH study, first convincingly demonstrated in a multinational field study that there is relation between learning (measured as reading ability) and noise exposure [19]. Reading comprehension and recognition memory were found to decrease with increasing aircraft noise level at school. Deficits in cognitive performance were seen at aircraft noise levels even below 50 dB(A).

4 Health risk assessment

In a serious document with the witty title “Death, DALY’s or Dollars”, de Hollander showed that for the political decision process it does not matter very much if environmental impact is evaluated in terms of money, health or mortality risk. The choice between one method or another depends on cultural and/or political preferences. From the technical point of view, validated methods are available to assess environmental impact of an activity. Even if it is not possible to assess absolute impacts, at least the ranking order of the alternatives can be established. The following formula defines the assessment of the *attributive fraction* (WHO). The attributable fraction (other terms: impact fraction, population attributable risk) describes the reduction in disease incidence that would be observed if the population were entirely unexposed, compared with its current (actual) exposure pattern.

$$AF = \{\Sigma(P_i * RR_i) - 1\} / \Sigma (P_i * RR_i)$$

where: AF= *Attributive Fraction*

P_i = Proportion of the population in exposure category *i*

RR_i = relative risk at exposure category *i* compared to the reference level

The DALY (and QALY) was developed by WHO and the World Bank to enable policy makers to make rational choices for medical treatment. To do this each clinical phenomenon is assessed to establish a weighting factor. According to the protocol designed to assess these weights, the factor takes into account (loss of) mobility, self-care, daily activities, pain/discomfort, anxiety/depression and cognitive function. In principle the DALY is calculated by:

DALY = NI (number of incident cases) x DW (disability weight) x LI (average duration of disability in years).

Although the procedure is not without critics, it can be used to rank policy alternatives. One critical point is the choice of the disability weights. This has to be done under strictly controlled conditions preferably by qualified staff, otherwise groups with different interests come to different weights. Over time consensus (within WHO) has been reached for most severity weights, or has been reduced to a manageable range. For example, severity weight of 0.01-0.033. 0.02-0.055, 0.35 and 1.00 have been used for annoyance, self-reported sleep disturbance, ischaemic heart disease and mortality, respectively.

5 Cost benefit

Cost benefit analysis is often a standard procedure in policy making, and in the European Commission this is mandatory. An important factor to carry out the analysis is an estimate of the benefits. Currently there are two methods for which sufficient proof is available: Contingent valuation and Hedonic pricing. The Working group Health and Socio-economic aspects provided the position paper “Valuation of noise” based on the willingness to pay data from Navrud [20]. The paper recommends to use a benefit of 25 € per household per decibel per year above noise levels of 50-55 L_{den}. Even if this figure has been criticized as being too low, it appears that most noise abatement measures have a positive cost benefit ratio. Hedonic pricing data come from studies on the house markets: it is found that real estate at higher noise levels have lower value then the same at lower noise levels. This is true for houses (for which there is extensive literature) but probably also for office buildings. The best estimate is that house prices loose 0.5% of their value per decibel over 50-55 Lden. The range of research results is between 0.2% and 1.5%, with a tendency for higher values for aircraft noise.

6 Quality targets

The recently issued Night Noise Guidelines expanded the Community guidelines on the issue of sleep disturbance, and concluded that although biological effects kick in as low as 30 dB L_{night}, 40 dB L_{night} should be an adequate health protection value, but proposed also an "interim target" of 55 L_{night}. An $L_{night,outside}$ of 30 dB(A) is considered as LOEL (lowest observed effect level) and an $L_{night,outside}$ of 40 dB(A) as LOAEL (lowest observed adverse effect level). The CALM network considered L_{den}/L_{night} values of 50/40 dB(A) as an optimum target that is defensible [21]. There seems to be a long term consensus that around 50 dB L_{den} (or their equivalent levels in other units) would be ideal, and 65 Lden the value the minimum that should be obtained to protect from serious health effects. The night time levels are 10 dB lower. The Environmental Noise Directive [22] choose implicitly for "targets" that are above the optimum targets in the preceding chapter. The lower thresholds for mapping (55 L_{den} and 50 L_{night}) delimit the area where the noise is considered a problem. The WHO Night Noise guidelines [9] give clear advice that from the health point of view the calculations of night time burden should start at 40 L_{night} and that action planning should at least contain actions to bring down the level to below 55 L_{night}.

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