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Noise and health in vulnerable groups: A review

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Abstract

Vulnerable or susceptible groups are mentioned in most reviews and documents regarding noise and health. But only a few studies address this issue in a concrete and focused way. Groups at risk most often mentioned in the literature are children, the elderly, the chronically ill and people with a hearing impairment. The other categories encountered are those of sensitive persons, shiftworkers, people with mental illness (e.g., schizophrenia or autism), people suffering from tinnitus, and fetuses and neonates. The mechanism for this vulnerability has not been clearly described and relevant research has seldom focused on the health effects of noise in these groups in an integrated manner. This paper summarizes the outcomes and major conclusions of a systematic, qualitative review of studies over the past 5 years. This review was prepared for the 10 th Conference on Noise as a Public Health Problem (ICBEN, 2011). Evidence is reviewed describing effects, groups assumed to be at risk, and mechanisms pertaining to noise sensitivity and learned helplessness.

Keywords: *Adverse effects, health, noise, vulnerable groups*

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Introduction

In the recently published guideline by the WHO [1] for the burden of disease from environmental noise, it is concluded that future epidemiological noise research will need to focus on vulnerable groups; some noise exposures may be worse for particular subgroups than for others such as children, older people and lower socioeconomic groups. This conclusion supports the notion that noise effects can and should be differentiated between subgroups. In most recent reviews [1],[2],[3],[4],[5] on noise and health, this topic has been touched upon, but evidence is still scarce and scattered. There are conceptual problems and the mechanisms for these vulnerabilities have not been clearly described, nor are the mechanisms necessarily the same for different groups at risk. Mechanisms best described in the literature pertain to noise sensitivity, which is primarily assumed to operate via differential physiological responses to noise, and via socioeconomic status, e.g., via learned helplessness.

The key terms are vulnerability, noise sensitivity, (noise) sensitive areas or place and high-risk groups. These concepts are defined as follows. Vulnerability refers to the susceptibility of a person, group, society or system to physical or emotional injury or attack. It has also been described as the degree to which people, property, resources, systems and cultural, economic, environmental and social activity is susceptible to harm, degradation or destruction on being exposed to a hostile agent or factor.

Noise sensitivity refers to the internal states (be they physiological, psychological and attitudinal or related to life style or activities) of any individual that increase their degree of reactivity to noise in general. Noise sensitivity has a strong genetic component, as was shown by Heinonen *et al.* [6] Noise sensitivity can also be caused by physical illness, such as constant migraine headaches, and sudden trauma, such as a head injury. Severe panic disorder may also be accompanied by oversensitive hearing, which in turn facilitates panic attacks. Ear infections, surgery and the use of some prescribed medications can also lead to this heightened reaction to noise.

In epidemiology, a high-risk group has been defined as a group of people in the community with a higher-than-expected risk for developing a particular disease, which may be defined on a measurable parameter, an inherited genetic defect, physical attribute, lifestyle, habit, socioeconomic and/or educational feature as well as the environment. [7]

An area or place is defined as noise sensitive (NS) if noise interferes with the normal activities associated with the area's use. Examples of NS areas include residential, educational, health and religious structures and sites and parks, recreational areas (including areas with wilderness characteristics), wildlife refuges and cultural and historical sites where a quiet setting is a generally recognized feature or attribute. [8]

Methods

Data sources and searches

The Medline and Scopus databases were searched to identify relevant peer-reviewed studies published during a 5-year period between April 2006 and April 2011. This period runs partly parallel with the ICBEN (the international commission on biological effects of noise) congress timeline, but allows for a longer period of 5+ years in order to fully cover the issue of vulnerable groups. A wide range of keywords was used related to noise exposure, vulnerable goups and health outcomes, which is presented in Annex 1 [Additional file 1]. In addition, the reference sections of previous systematic reviews, key papers, conference proceedings and international reports on vulnerable groups as well databases of websites dealing with the issue of noise and vulnerability [i.e., the World Health Organisation (WHO), Policy Interpretation Network on Children's Health and Environment (PINCHE) [9] and the European Network on Noise and Health (ENNAH)] were checked for potentially relevant references.

Inclusion and quality criteria

There was a language restriction for English, French and German papers. All studies were selected that concerned environmental quality in relation to noise, health and susceptible groups. Studies that did not explicitly deal with effects were, in most cases, excluded.

Results

Study characteristics

The original literature search yielded 212 papers, of which 71 were *a priori* eligible to be included in the review based on the crude criteria described above. Several papers were excluded because they did not give any information on the effects of noise. Finally, 62 papers were included in the review, of which 37 pertained to primary school children, 15 to (young) adolescents, 2 to pre-school children and 4 papers to neonates. Four papers concerned the effects of noise in specific patient groups such as children with autism, [2] asthma [1] and attention deficit hyperactivity disorder. [1] The eldery were addressed in four papers and another four addressed all age groups and/or life span exposures. Remarkably, few studies dealt with noise sensitivity, while this may be key to understand susceptibility, sensitive moments of the day, sensitive places and sensitive periods in the life course. An additional search in Medline and Scopus Databases yielded eight studies on these related topics for the past 5 years.

Health effects most frequently described in the literature were annoyance, sleep disturbance, cardiovascular disease, cognitive effects and effects on hearing. Risk groups most often mentioned in relation with environmental noise in the literature were children, older people, chronically ill people and the hearing impaired people. Groups potentially also at risk were noise-sensitive people, people with a low social economic status, people suffering from tinnitus, shift workers, mentally ill people (schizophrenia, autism) and foetus and neonates. Especially regarding hearing impairment, there was some overlap between hearing impairment as outcome and hearing impairment as a risk factor or indicator of susceptibility to noise. The overview of evidence is first structured along these health endpoints and theoretical risk groups. Next, evidence regarding the mechanisms of noise sensitivity and learned helplessness are discussed in more detail.

Annoyance

van Kempen *et al*. [10] showed that the exposure-annoyance curve of schoolchildren (aged 9-11 years) for aircraft noise, overall, has the same pattern as in adults. However, children score lower on annoyance at the high end of the scale, and somewhat higher at the lower end. These findings confirm the conclusion of Babisch; [11] In a recently published study, Babisch *et al*., [11] concluded that German children aged between 8 and 14 years were considerably less frequently annoyed by road traffic noise at home than adults.

Very few studies are available on annoyance reaction in older people. There is no evidence that people above 60 years respond differently to environmental noise. [12] Based on the analysis of a large metadata set (N = 62,983), van Gerven *et al*. [13] found evidence of a non-linear relation; results revealed an inverted U-shaped pattern for both road and air traffic noise plotted against age. The lowest frequencyof highly annoyed were found in both the youngest and the oldest groups. These effects were independent of noise level and noise sensitivity.

A study in Beijing [14] among students revealed that the extremely high levels of exposure to traffic noise (64.0 dBA to 79.2 dBA) resulted in a percentage highly annoyed of up to 39% on the ISO verbal annoyance scale, and 50% according to the numerical scale.

Sleep disturbance

Evidence has indicated [15] that children are less sensitive to awakenings and sleep-cycle shifts, but more sensitive to physiological effects such as blood pressure (BP) reactions [5],[16],[17] and related motility. [18]

Muzet, [16] in his review, concluded that there is only anecdotal evidence that older people are more at risk for sleep disturbance due to noise. Other potential vulnerable groups are people with a somatic or mental disorder and shift-workers. [16] Earlier suggestions that long-term health effects of sleep disturbance depend on the person's vulnerability and/or sensitivity [18],[19],[20] are not supported by more recent evidence.

Cardiovascular effects

Analysis on the pooled data set (Heathrow, Schiphol) of the RANCH study [21] indicated that aircraft noise exposure at school was related to a statistically non-significant increase in BP and heart rate in children. Road traffic noise showed an unexplained negative effect. Babisch and van Kamp [22] (and a later review of UK studies [23]) concluded that there was an inconsistent association between aircraft noise and children's BP. In their recent review, Paunovic *et al*., [24] concluded a tendency toward positive associations, but observed large methodological differences between studies. A study among children aged 8-14 years by Babisch *et al*., [25] concluded that road traffic noise at home as a stressor could affect children's BP. There is some evidence that short-term cardiovascular reactions during sleep are more pronounced in children. [26] Lepore *et al*., [27] concluded that compared with quiet-school children, noisy-school children had significantly lower increases in BP when exposed to either acute noise or non-noise stressors, indicative of a generalized habituation effect. Studies in Serbia [28],[29] among schoolchildren and pre-school children indicated a raised BP among children from noisy schools and quiet residences compared with children from both quiet environments. There is no consistent evidence that the effect of traffic noise on cardiovascular diseases increases with age. [30] Bodin *et al*., [31] found strong evidence for an age effect in the noise BP association, with a stronger relation in the middle aged; age group-specific models could account for differences in prevalence in future studies.

A study among 30 male and female participants aged 18-32 years [32] concluded that environmental noise leads to a significant increment in both systolic and diastolic BP. The effects were significantly associated with an increment of 5 dBA both in transient as well as in sustained effects (lag time > 30-60 min), especially in females.

There is a differential, but inconclusive, effect regarding gender differences in cardiovascular effects of noise. [4],[33] Finally, Babisch showed that people with prevalent chronic diseases run a slightly higher risk of heart diseases as a result of traffic noise than those without heart diseases. [33]

Physiological effects and quality of life

A study in France [34] among 10-year-old schoolchildren showed that school noise exposure was associated with fatigue, headaches and higher cortisol level indicative of a stress reaction. These findings are supported by a Swedish study, [35] which found increased prevalence of fatigue, headache and reduced diurnal cortisol variability in relation with classroom Leq during school day levels between 59 and 87 dBA. A cross-sectional study in Nigeria [36] among children frequenting a school near a major road (noise range: 68-85 dBA) found at least some annoyance and concentration disturbance in 70% of the children. Fatigue and lack of concentration came forward as the most prevalent noise-related health problems.

Parra *et al*., [37] report that in people over 60 years of age living in Bogota, road traffic noise was negatively related to both the physical and the mental dimension of health-related (HR) quality of life.

Cognitive effects

Based on the RANCH study of exposures around three major European airports, Clark *et al*., [38] reported that exposure at home was highly correlated with aircraft noise exposure at school and demonstrated a similar linear association with impaired reading comprehension after adjustment for a range of confounders. Stansfeld *et al*., [39] concluded that night exposures does not add to these effects of daytime exposures to aircraft noise. Likewise, Kaltenbach *et al*., [40] found exposure to aircraft daytime noise of 50 dBA and over to be associated with learning difficulties in schoolchildren. Road traffic noise exposure at school was not associated with reading comprehension in the RANCH study. Ljung *et al*., [41] concluded that road traffic noise impaired reading speed and basic mathematics, but had no effect on reading comprehension or on mathematical reasoning. Irrelevant speech did not disrupt performance on any task. Klatte *et al*., [42] found that serial recall of visually presented digits was severely disrupted by background irrelevant speech. A later study [43] replicated the findings regarding irrelevant background speech. Noteworthy is the fact that the children did not consciously realize these detrimental effects of irrelevant speech. Train noise exposure did not show comparable effects.

Shield and Dockrell [44] related in- and outside-noise exposure at school with standard test scores for literacy, mathematics and science in children aged 7-11 years in London. The results revealed an association between noise and performance on these tests after adjustment for socio-economic factors, especially in the older children. However, a recent study of Xie *et al*., [45] in secondary schools in Greater London did not support these findings.

In a small study ($N = 20$) on the effect of climate, light and noise in the work environment, Fosnaric and Planinsec [46] found a significant effect of noise on the work performance of male adolescents.

Hearing effects

Studies on hearing loss due to noise in children are rare. Within the framework of the PINCHE project, Bistrup *et al*., [47] concluded that noise can have auditory effects on children, but most effects are long term and cumulative. They advise to describe the effects of noise on children from a life-course perspective in order to illustrate the prospects of cumulative effects. A study [48] among children of highly noise-exposed mothers during pregnancy showed no hearing impairment.

In the past 5 years, several studies have addressed the issue of hearing disorders and loss in adolescents as a result of recreational noise. Rosanowski *et al*., [49] found no pure tone hearing loss but found transient effects on hearing and tinnitus immediately after exposure. Martinez-Wbaldo Mdel *et al*., [50] reported high-frequency hearing loss in 21% of the high-school students in Mexico, which was primarily related to frequent exposure to music at discotheques and pop-concerts, the use of personal devices and noise exposure in school workshops. A study in Brazil [51] among young adults confirmed these findings, indicating that a substantial percentage of the participants reported temporary tinnitus (69%) after attending discos and concerts and listening to music through headphones. Tinnitus complaints were more frequent among females (41%) than among males (27%). A similar study in Turkey [52] also found a high prevalence of (transient) tinnitus in young adolescents due to loud music. Noise-induced hearing loss at a young age due to recreational music and personal devices was reviewed by Harisson. [53] An American study [54] revealed a prevalence of approximately 6% perceived hearing loss and 13.5% of prolonged tinnitus.

The effects of noise and smoking were studied in a stratified sample of 440 people between 21 and 50 years by El Zir *et al*., [55] The results showed an effect of smoking on hearing in all age groups but an interaction effect with noise only in the group older than 40 years.

In a recent study of Heinonen *et al*., [56] noise sensitivity was associated with self-reported hearing disability among all subjects, but especially in women and younger subjects (50 years or less). Finally, Baur *et al*., [57] reported significant negative effects of noise exposure, painkillers, overweight and cardiovascular diseases on hearing loss. A positive effect of moderate alcohol consumption was shown in the elderly.

Miscellaneous outcomes for specific risk groups and outcomes

Linares *et al*., [58] studied hospital admissions of children younger than 10 years old and found an association between road traffic noise levels and admission for respiratory disease, pneumonia and organic diseases after adjustment for air pollution effects, meteorological circumstances, influenza epidemics and pollen concentrations. An effect of social economic status could not be ruled out based on the presented information. In a birth cohort of 652 children, Bockelbrink *et al*., [59] found an association between noise annoyance (specifically during the night) and prevalence of physician-diagnosed asthma attacks in girls.

The few studies [60],[61],[62] on neonates at the ICU of hospitals have concentrated on noise levels only and potential measures to reduce these. No data are available regarding the short- and long-term health effects.

Russo *et al*., [63] compared speech-evoked responses between normal children and children with autism under a quiet and noisy condition. Normal children showed delayed reaction times under the noisy conditions, whereas autistic children showed delayed times under both conditions; children with attention deficit syndrome perform as well under quiet conditions as normal children do under noisy conditions.

Mechanisms

Berry and Flindell [3] concluded in their review that evidence shows that noise-sensitive (NS) people were more susceptible to cardiovascular effects. This ties in with the role of annoyance as a mediating factor. Babisch *et al*., [25] only found an effect of NS on cardiovascular effects when NS, annoyance and exposure were assessed before the cardiovascular outcomes (prospective studies). White *et al*., [64] compared physiological effects of task performance between highly NS and a non-sensitive group. Both mean heart rate and sympathovagal balance of non-NS subjects were responsive to the change in circumstances between conditions. This was not the case for high NS participants. Shepherd *et al*., [65] found that NS was associated with HR quality of life. Annoyance and sleep disturbance mediated the effects of NS on health. Schreckenberg *et al*., [66] concluded that NS people were more critical of their environmental quality, in particular with regard to air traffic. This phenomenon was earlier referred to by Weinstein as "critical tendency." [67] Fyhri and Klaeboe [68] concluded that only NS was related to hypertension and chest pain, while no relationships between noise exposure and health complaints were identified. It was concluded that it is conceivable that individual vulnerability is reflected both in ill health and NS. Heinonen *et al.*, [69] found that cardiovascular mortality was significantly increased only in NS women. Based on this, it was concluded that NS may be a risk factor for cardiovascular mortality in women, which is a slightly different interpretation than that suggested by Fyhri and Klaeboe. [70] No main effect of NS was observed by Ljungberg and Neely [71] in cognitive after-effects of vibration and noise exposure.

Ryu and Jeon [72] found NS to have a greater influence on the percentage of highly annoyed by indoor noise than outdoor noise. Marks and Griefahn [73] report a high correlation between noise sensitivity and subjective sleep quality in terms of decreased restoration and calmness, difficulty to fall asleep and body movements. The results suggest that noise-induced sleep disturbance is mediated by NS.

Very few studies addressed the role of socioeconomic factors. Theoretically, this relation would operate via learned helplessness [74] and unequal distributions of noise in the population. Low socio economic status (SES) groups/areas might be more at risk due to accumulations of exposures at residential level (noise, air pollution, etc.) and of residential and work exposures. In the USA and UK, an association was previously found between income level and exposure levels. [75] In the Netherlands, no such SES differences were confirmed, except for rail noise. Both at the higher and at the lower ends of the SES gradient, increased noise exposures were found. [76] Likewise, Fyhri and Klaeboe [70] did not find a SES-related noise distribution in Oslo, but they did find an income-mediated association in a medium-sized city.

Conclusions

Vulnerable groups regarding environmental noise have been understudied, are generally underrepresented in study populations and evidence of differential effects is still highly anecdotal. As a consequence, clear effects are few and this is partly due to the lack of targeted and well-designed studies making clear comparisons between the general population and the potentially susceptible groups and quantifying these differences in terms of noise levels. Setting specific limit values to protect susceptible groups is not yet possible based on the available evidence, although some suggestions have been made in the literature. In the Night noise guidelines, [18] for example, it has been suggested that night time exposure levels above 40 dB more severely affect vulnerable groups.

Effects of noise in schoolchildren are the best documented. The available evidence shows that children are less vulnerable for annoyance than adults, but more vulnerable for cognitive effects of noise. They are not *per se* more vulnerable as a group, but more at risk because of less-developed coping strategies, and they are in a sensitive developmental period. This is indicative of a life phase effect rather than an age effect. Children seem to be less vulnerable for awakenings due to noise but more vulnerable for physiological effects during sleep and related motility. There is some evidence that annoyance from both road- and air traffic noise predicts asthma prevalence in children (both self-reported and diagnosed). Evidence does not indicate that the elderly are more vulnerable to noise in terms of annoyance and sleep disturbance. Age-specific comparisons rather show an inverted U-shaped relation and indicate that both young and older people are less at risk as far as annoyance and disturbance are concerned. But, possibly, the elderly are more vulnerable regarding cardiovascular effects, and this may be a combined effect of air pollution and noise. [77] The role of noise annoyance and noise sensitivity in this relation is still inconclusive. Noise sensitivity-related effects might be part of a more generic vulnerability effect, which could be psychologically and/or physiologically based. Gender differences in terms of vulnerability for cardiovascular effects should also be further studied. A further distinction between susceptible people, places and periods might be useful for future research. More attention to specific groups at risk is warranted, such as the mentally ill, shift-workers and people suffering from tinnitus. Also, the distribution of noise over SES groups deserves more attention as well as the accumulation of exposures (noise and air), the accumulation of residential and work-related exposures and places with less opportunity for recovery from daily stressors (lack of restoration). It may also be fruitful to study the differential effects of noise from a more contextual viewpoint and take life course- and life phase-related aspects into account. This includes looking at studies into the health effects of noise in groups based on, e.g., social economic status, working situations and places. Assuming a joint effect of co-exposures like noise and air pollution, or different noise sources, studying susceptible groups based on these would shed more light on these joint effects. It would also include looking at specific susceptibility for noise during the life stages and an accumulation of risk during the life course. To further this field, it is necessary in future studies to present and compare subgroup-specific exposure effect relations. Generic use of the term "vulnerable groups" should be avoided as the mechanisms are quite different and maybe more important: They vary in time, place and across contexts. Groups at risk or susceptible groups, periods or places would, in most cases, be more appropriate terms to use and are less stigmatising than the term vulnerability.

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