Noise effects on children's cognition - WHO work on noise, Burden of Disease (BoD) and Disability-Adjusted Life Years (DALY)

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INTRODUCTION

It has been suspected for many years that children's learning and memory are negatively affected by noise. Over 20 studies have shown negative effects of noise on reading and memory in children (Evans & Hygge 2007; Evans & Lepore 1993): epidemiological studies report effects of chronic noise exposure and experimental studies report acute noise exposure. Tasks affected are those involving central processing and language, such as reading comprehension, memory and attention (Haines 2001a, 2001b, Evans & Maxwell 1997; Cohen et al. 1973). Exposure during critical periods of learning at school could potentially impair development and have a lifelong effect on educational attainment.

Evidence from recent well-controlled epidemiological studies with representative samples of children has also made it possible to start to quantify the magnitude of noise-induced impairment on children's cognition and identify the relative contribution of different sources of noise. Such quantifications, albeit initially crude, will in the long run help to estimate and quantify how much cognitive development individual children could be expected to lose because of noise, and the economic impact of this for learning in schools. In turn, such estimates will be also of value for making projections on the societal level, including political decision about any sociodemographic redistribution of noise exposure.

Definition of outcome

Cognitive impairment is not an outcome of a clinical diagnosis. It is therefore not possible to derive a conventional exposure–risk relationship suitable for calculating burden of disease. Lopez et al. (2006) defined cognitive impairment as "delayed psychomotor development and impaired performance in language skills, motor skills, and coordination equivalent to a 5- to 10-point deficit in IQ". Contemporaneous cognitive deficit is defined as "reduction in cognitive ability in school-age children, which occurs only while infection persists".

These definitions are not helpful and not readily applicable to the studies reported on noise and cognition in children. None of the studies has explicitly employed IQ as an end-point and the confining of any reduction in cognitive ability to the duration of the noise exposure is too restrictive. Therefore, our case definition of noise related cognitive impairment is:

> Reduction in cognitive ability in school-age children that occurs while the noise exposure persists and will persist for some time after the cessation of the noise exposure.

Summary of evidence linking noise and cognitive impairment in children

The extent to which noise impairs cognition, particularly in children, has been studied with both experimental and epidemiological designs. The epidemiological studies report effects of chronic noise exposure and the experimental studies of acute noise exposure. The studies relevant to children's cognition are not many and do not al-

ways meet strict methodological criteria. Nevertheless, there are three recent studies that meet basic methodological quality criteria and are also comparable with each other in terms of the cognitive functions measured.

One of the most compelling studies in this field is the naturally occurring longitudinal quasi-experiment reported by Evans and colleagues, examining the effect of the relocation of Munich airport on children's (9–10 years, N = 326) health and cognition (Evans et al.1995, 1998; Hygge et al. 2002). In 1992, the old Munich airport closed and was relocated. Prior to relocation, high noise exposure was associated with deficits in long-term memory and reading comprehension. Two years after the closure of the airport, these deficits disappeared, indicating that effects of noise on cognition may be reversible if exposure ceases. Most convincing was the finding that deficits in the very same memory and reading comprehension tasks developed over a two-year follow-up in children who became newly exposed to noise near the new airport.

The recent large-scale RANCH study, which compared the effect of road traffic and aircraft noise on children's (9–10 years, *N* = 2,844) cognitive performance in the Netherlands, Spain and the United Kingdom, found a linear exposure–effect relationship between long-term exposure to aircraft noise and impaired reading comprehension and recognition memory, after taking a range of socioeconomic and confounding factors into account (Stansfeld et al. 2005). No associations were observed between long-term road traffic noise exposure and cognition, with the exception of episodic memory, which surprisingly showed better performance in high road traffic noise areas. Neither aircraft noise nor road traffic noise affected attention or working memory.

A study of ambient noise exposure (predominantly road and rail sources) of fourth-grade children living in the Tyrol mountain region (Lercher et al. 2003) compared three cognitive measures for schoolchildren (mean age 9–7 years, *N* = 123) exposed to 46 or 62 dBA L_{dn}. The two sociodemographically homogeneous samples differed only in their noise exposure range (M = 46.1 L_{dn} vs M = 62 L_{dn}). Long-term noise exposure was significantly related to both intentional and incidental memory. The improvement in cognitive performance in the quieter group was estimated at 0.5 % (recall prose and recognition) to 1 % (free recall) per dB. The authors note that the magnitude of the effects shown was smaller than those uncovered in earlier airport noise studies.

Both the RANCH and Tyrol studies indicate that aircraft noise may be worse for cognition than road traffic noise. For aircraft noise, exposure evidence from the Munich study seems to indicate that L_{Aeq} = 60 dB may be a dividing line, but the RANCH study results suggest more of a linear association between aircraft noise exposure and impairment of reading comprehension. For ambient road and rail noise, the Tyrol study suggests that effects occur around L_{dn} = 60 dB.

Other field studies of children have had some methodological limitations, which make them less relevant as evidence. For example, the testing of cognitive capacities took place in noisy conditions for the noise-exposed and in quieter conditions for the children in the control groups. Testing in silent conditions would have been preferred, in order to compare the noise effect on memory and learning between exposure and control groups (Bronzaft 1981; Bronzaft & McCarthy 1975; Green et al. 1982; Haines et. al. 2002; Lukas et al. 1981). Also, for some studies, the socio-demographic variables and different reading curricula between the schools were not fully adjusted or controlled for.

METHODS

Exposure–response relationship

Only the Tyrol study (Lercher et al. 2003) has used the noise indicator L_{dn}. The Munich study used L_{eq24} and the RANCH study predominantly used L_{eq16}. The L_{dn} and L_{eq} metrics are not directly equivalent: L_{dn} is always equal to or larger than L_{eq}, with the following differences between L_{dn} and L_{eq} (T. Gjestland, personal communication, 2006):

- evenly distributed traffic flow, + 6.4 dB
- evenly distributed 07:00–22:00, no night traffic, + 1.9 dB
- 10 % of traffic during 22:00–07:00, + 2.9 dB.

Although it is not clear which noise metric is the most adequate, L_{dn}, which combines daytime and nighttime exposure, was here chosen for examining the effects of aircraft noise on cognition. However, this issue may be more complicated for other noise sources.

Figure 1 shows the exposure–response curves from the different epidemiological studies. This can be summarized in quantitative terms. For the field studies in 1, memory recall and reading have average slopes of around 2 % per L_{dn}, as calculated by the mean of the slopes of the six lines. Thus, for recall and reading, it is expected that a reduction of the chronic noise level by 5 L_{dn} would result in improved performance by 10 %. As noted above, the only available road traffic noise study (Lercher et al. 2003) had a less steep slope. The fact that we do not have much data from road traffic noise exposure set a limit to the generality of our conclusion, but the results of studies on aircraft noise, albeit few, are nevertheless consistent.

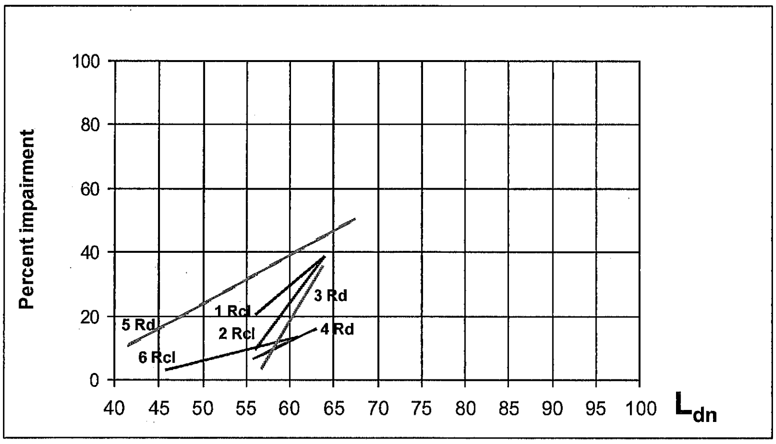

Figure 1: Exposure-response curves from different epidemiological studies. Rd = reading, Rcl = memory, recall. 1-4 = Hygge et al. (2002), 5 = Stansfeld et al. (2005), 6 = Lercher et al. (2003).

To obtain the exposure–response relationship, we need to use the information above to determine an approximate curve. Assuming that 100 % of those exposed to noise are cognitively affected at the very high noise levels, e.g. 95 L_{dn}, and that none are affected at a safely low level, e.g. 50 L_{dn}, a straight line (linear accumulation) connecting these two points, as was done in Fig. 1, can be used a basis for approximations. Note that such a straight line is an underestimation of the real effect. For theoretical reasons, based on an assumed underlying normal distribution, the true curve should have the same sigmoidal function form as the curve in Fig. 2. Within the noise exposure bracket 55–65 L_{dn}, the straight line and the solid line sigmoidal distribution agree on approximately 20 % impairment. In the bracket 65–75 L_{dn}, the number should be in the range of 45–50 % and above 75 L_{dn} in the range of 70–85 %.

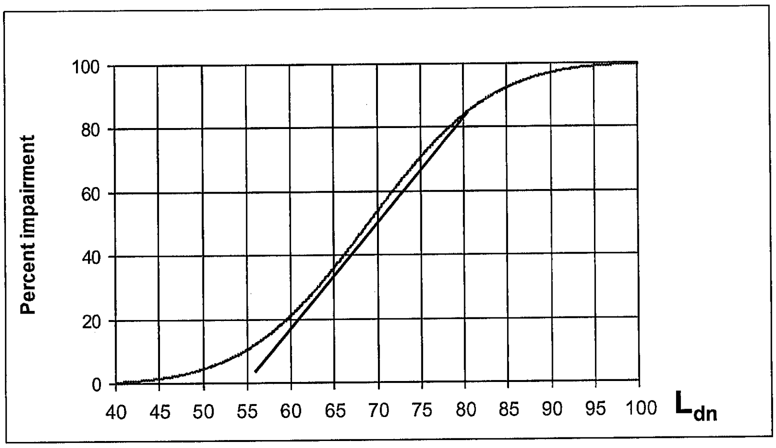

Figure 2: A sigmoidal S-function from the normal distribution and a straight line approximation as in Figure 1. Note that within the noise exposure bracket < 60 L_{dn}, the straight line underestimates the impairment

Disability weight

Lopez et al. (2006) suggested DWs for different cognitive impairments ranging from 0.468 (e.g. Japanese encephalitis) or 0.024 (e.g. as a result of iron deficiency anaemia). Contemporaneous cognitive deficit was given a DW of 0.006. Thus, this is a very conservative choice to go with the definition of contemporaneous cognitive deficit and a DW of 0.006 in estimates of the noise-related impairment of children's cognition.

There would be no mortality due to cognitive impairment, so estimation of YLD per year will be sufficient to estimate the total DALYs.

EBD calculations - Assumptions

Disability weight

Knowing the approximate distribution across age groups of the population in a country, assuming a certain DW weight (0.006) and making assumptions about how many percent of the children are fully affected in the noise exposure brackets, a tentative burden of disease from cognitive impairment stemming from noise exposure in children aged 7–19 years can be calculated and expanded to the WHO EUR A epidemiological sub-region (Lopez et al. 2006). This is done in Table 1.

No noise after-effect

Note that the calculations rest on the assumption that the noise effects are there only when people are exposed. There is no assumption made that the inflicted noise-induced disability lasts longer than the noise exposure. It would not be unreasonable to set a case also for lasting cognitive effects of noise also after the cessation of exposure, but that has explicitly not been done here.

Percentage of noise exposed children

In Table 1 the distribution of the population across the age groups is taken from Swedish population data in late 2004 was taken to calculate the percentage of children aged 7-19 years. In Sweden, 23.9 % of the population are aged under 20 years and 16.53 % were in the age range of the mandatory school system in 2004. In 2004, there were 1 489 437 school-aged children in Sweden. It can be noted that the proportion of the population up to 19 years (23.9 %) fits closely with the 24.2 % for the EU in 1998 (van den Hazel & Zuurbier 2005).

Table 1: Estimated DALYs per year per million of the population from children aged 7–19 in the EUR A epidemiological sub-region

Age group and noise exposure level	Percentage of population exposed to given noise level	Percentage of population who will develop cognitive impairment	Number impaired per million	DALYs lost per million
7–19 years, < 55 L_{dn}	11.24	0	0	0.0
7–19 years, 55–65 L_{dn}	3.14	20	6 281	37.7
7–19 years, 65–75 L_{dn}	1.82	50	9 090	54.5
7–19 years, > 75 L_{dn}	.33	75	2 475	14.9
All other age groups	83.47	0	0	0.0
Total	100.00		17 846	107.1

RESULTS

Percentage of noise exposed children

There are no relevant figures for how many children are exposed to different noise levels. What are available are estimates of the percentage of people exposed to noise at different levels in the EU. Roovers et al. (2000) reported that stated that around 68 % of the population is exposed to L_{dn} levels < 55, 19 % to 55–65, 11 % to 65–75 and 2 % to > 75. Although statistics for the specific countries within geographical regions such as the EU may vary the figures in Roovers et al. (2000) were extrapolated estimate how many percent of the children (expressed as percentages of the whole population) were exposed to noise.

Likelihood of cognitive impairment when noise exposed

As argued above, Figure 1 indicated that within the noise exposure bracket 55–65 L_{dn}, there is approximately 20 % impairment. In the bracket 65–75 L_{dn}, the number should be in the range of 45–50 % and above 75 L_{dn} in the range of 70–85 %. Thus, in Table 1 the values of 20, 50 and 75 % were in inserted as an estimated of how many children will be cognitively impaired.

Number of cases of and YLD from cognitive impairment caused by environmental noise

Combining the number of children exposed with the likelihood of cognitive impairment if exposed, the number of children with noise-induced cognitive impairment can be calculated. To estimate YLD due to the cognitive impairment, this number is multiplied by the DW of 0.006 (Table 1).

The number of DALYs per million children aged 7–19 in the EUR A is estimated to 107.1, The absolute DALY for the EUR A countries, with an estimated total population of 420,503 million, is therefore 45 036.

Uncertainties, limitations and challenges

Source of noise

The slopes reported in Figure 1 are mainly for aircraft noise. In contrast to the Munich study, which focused on aircraft noise, the RANCH study also included road traffic noise. But for road traffic noise, there was no indication of a significant impairment of children's cognition. As an explanation, the authors pointed out that aircraft noise, because of its intensity, the location of the source, and its variability and unpredictability, is likely to have a greater effect on children's reading than road traffic noise, which might be of a more constant intensity. Thus, it is conceivable that aircraft noise is more damaging than road traffic noise for children's cognition. This may also be true when the L_{dn} level is controlled for, which has been reported for children's memory in an experimental acute noise study (Hygge 2003).

Even though there may be a degree of difference between aircraft and road traffic noise, acting on the safety principle would suggest treating them as equally damaging to children's cognition and to assume that there is approximately the same response effect regardless of noise source. This may, however, tend to overestimate the effects of road traffic noise.

Design of epidemiological studies

It should be noted that the RANCH study was a cross-sectional study in contrast to the prospective, longitudinal Munich study. This may make the Munich study more powerful in picking up unconfounded cause–effect relationships between noise exposure and outcomes.

Possibility of long-term cognitive impairment from chronic noise exposure

The DALYs calculated in Table 1 have not taken into account any lasting or long-standing impairment of cognitive functioning that could occur as a result of long-term noise exposure. Our calculations are restricted to the period in children's life when they attend primary school, assuming that the impacts of noise are negligible on the cognitive function of adults. This assumption is very conservative, however, because it is more likely that children who have passed through the mandatory school system in a noisy environment would live with a long-term consequence of cognitive impairment. They are also more likely to live in a noisy environment even after the schooling period, which is more likely for children who go to school in areas exposed to aircraft noise. It would be realistic to assume that the impaired cognitive function will carry over to the years after the schooling period. If future studies provide an estimation of the severity and the duration of such chronic effect of noise on cognitive function, the calculation of DALYs should be updated.

Assumption of the duration of the impact

There is some evidence from the Munich study (Hygge et al. 2002) that after the cessation of exposure to aircraft noise, children (age 9–11 years) recover within 18 months to the cognitive performance levels of their year-mates who were not exposed to much aircraft noise. Thus, it is possible that, at least for young children, chronic noise effects are reversible and that the DWs will diminish with increasing age. However, we assumed in our calculation that the effects are temporary and recovery is quicker, yielding YLD values that are conservative.

Assumption of the exposure–risk relationship

As pointed out above, with reference to the linear and sigmoidal accumulation of effects in Figure 3.2, we have most likely not overestimated the fractions of children affected in the noise exposure ranges 65–75 L_{dn} (50 %) and > 75 L_{dn} (75 %). Further, we might have underestimated the average DW (0.006) for those affected by the higher level of noise. These two conservative assumptions may have led to a significant underestimation of the real DALYs in the EUR A epidemiological sub-region in Table 1. For example, if DW doubles and quadruples to 0.012 and 0.0024 in the exposure brackets 65–75 L_{dn} and > 75 L_{dn}, respectively, the DALYs will be much greater than shown in Table 1.

Policy considerations

An alternative to viewing the noise-induced cognitive impairment of children from a burden-of-disease perspective is to analyze the impairment in terms of wasted learning units. The learning units could be given a monetary value in wasted teaching hours in schools – wasted for the teachers, the pupils and society. Therefore, the societal impact will probably be larger than the impact reflected by DALYs, which solely estimate the impact on specific cognitive impairment. A calculation of wasted learning units instead of DALYs is probably a more complicated task, with many more uncertain parameters. For the time being, DALYs from noise-induced impairment of cognition in children, together with DALYs from other environmental risks, may provide evidence for prioritizing policy options, such as lowering recommended noise levels in control guidelines for schools and learning.

CONCLUSIONS

Reliable evidence indicates the adverse effects of chronic noise exposure on children's cognition. There is no generally accepted criterion for quantification of the degree of cognitive impairment into a DW. However, it is possible to make a conservative estimate of loss in DALYs using the methods presented in this chapter. It is important to consider the assumptions, uncertainties and limitations in the methods when interpreting the estimated values of END.

Note. This paper is a summary of a chapter (Hygge 2011) in a recent WHO-publication on *Burden of Disease from environmental noise in Europe*.

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The long-term effects of aircraft noise exposure on children's cognition: findings from the UK RANCH follow-up study

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INTRODUCTION

Exposure to transport noise is an increasing and prominent feature of the urban environment. The RANCH project (Road Traffic Noise and Aircraft Noise Exposure and Children's Cognition and Health), the largest study of noise and children's cognition undertaken to date, examined the effects of aircraft noise and road traffic noise exposure at primary school on the cognitive performance of 2,844 9-10 year old children attending 89 schools around Heathrow (London), Schiphol (Amsterdam), and Barajas (Madrid) airports. The study found linear exposure-effect relationships between aircraft noise exposure at school and children's reading comprehension and recognition memory (Clark et al. 2006; Stansfeld et al. 2005).

Whilst previous studies had demonstrated effects of chronic aircraft noise exposure on primary school children's reading comprehension and long-term memory, comparing children with high noise exposure with those with low noise exposure (Haines et al. 2001a; Hygge et al. 2002), the RANCH study was the first to examine exposure-effect relations and to compare the effect of noise exposure on children's cognition across countries. The development of cognitive abilities such as reading are important not only in terms of educational achievement but also for subsequent life chances and adult health (Kuh & Ben-Shlomo 2004). To understand the causal pathways between noise exposure and cognition, and design preventive interventions, there is a need to study these associations longitudinally. However, few longitudinal studies have examined the effects of persistent exposure throughout the child's education: a study over only a one-year period found that deficits in reading comprehension persisted and that children did not adapt to their noise exposure (Haines et al. 2001b). Studies of noise abatement suggest that a reduction of noise exposure eliminates previously observed reading deficits (Bronzaft 1981; Hygge et al. 2002) but studies of the long-term consequences of noise exposure during primary school for later cognitive development have not been conducted.

This study followed the UK sample of the RANCH cohort to examine the long-term effects of aircraft noise exposure at primary school on children's reading comprehension. This paper examines whether children who attend aircraft noise exposed primary schools experience impaired reading comprehension during secondary school, compared with peers who were not exposed to aircraft noise at primary school. The paper also examines associations between aircraft noise exposure at secondary school and reading comprehension.