THE EFFECTS OF ENVIRONMENTAL NOISE ON CHILD HEALTH AND LEARNING — A REVIEW OF INTERNATIONAL RESEARCH

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Abstract: Impairments of early childhood development and education by environmental pollutants such as noise, may have life long effects on achieving academic potential and health. In this article the non-auditory health effects of noise on children will be reviewed with a focus on current research evidence from international studies. In studies examining the effects of chronic aircraft, rail and road traffic noise on children there is consistent evidence that noise exposure adversely affects child cognitive performance. Noise exposure has also been consistently associated with noise annoyance and impaired well-being. There is moderate evidence that chronic noise exposure affects motivation, blood pressure and catecholamine hormone secretion. There is equivocal evidence that chronic noise exposure affects child mental health and sleep disturbance. Intervention studies should be a research priority area, because they can provide an evidence base to inform policies and measures to protect children from the adverse effects of noise. In addition, future studies are required to provide a more precise insight into the mechanisms that underlie child noise effects and the identification of vulnerable subgroups.

1. INTRODUCTION

There is consistent research evidence that chronic exposure to environmental noise leads to impaired cognitive function and health in children.[1, 2] In the last 20 years there has been increased empirical research investigating the effects of noise on children, with the Los Angeles Airport Study,[3,4] the Munich Airport Study[5,6], the Schools Environment and Health Study[7,8] and the West London Schools Study[9] around Heathrow Airport in London, in New York City,[10] and the Sydney Airport Health Study.[11] Children may be more susceptible to environmental stress than adults for a variety of reasons including: less cognitive capacity to understand environmental issues and anticipate stressors and a lack of well-developed coping repertoires.[12], [13] Impairments of early childhood development and education by environmental pollutants such as noise, may have life long effects on achieving academic potential and health.[13] In this review article we will summarise the international literature on non-auditory health effects of noise on children. We will conclude with a summary of the main effects and the requirements for future research.

2. NON-AUDITORY HEALTH EFFECTS OF NOISE ON CHILDREN

Cognitive performance

The most widespread effects of noise found in children are cognitive impairments, though these effects are not uniform across all cognitive tasks.[1,12] There is empirical evidence from laboratory[14–18] and field studies[5,6] suggesting that complex tasks that involve central processing demands and language comprehension, such as reading, attention, problem solving and memory are more affected by noise exposure than simple tasks. This effect of environmental stress on cognitive tasks with high processing demands is widely accepted in the environmental stress literature examining the general sources of environmental stress on cognition.[12,19]

These are the specific effects that have been found in relation to noise exposure and child performance:

1) poorer reading ability and school performance on national standardised tests[5,10, 20–27]
2) poorer memory that requires high processing demands of semantic material [5,6,15,28–31]
3) deficits in sustained attention and visual attention[8,31–38]
4) poorer auditory discrimination and speech perception[3,5,10,12,22,37]

Some of the earlier research examining noise effects in children has methodological flaws limiting the conclusions that can be drawn from the data. These flaws include: data were not provided to indicate how well socio-economically matched the noise exposed children were to the control sample,[35–37] the sample size was not large enough (most of the studies); not enough schools to rule out a school effect confounding the results,[3,4,7,17,35] statistical methods were not sensitive enough,[38] and most studies were cross-sectional. The results from field studies that control for socio-economic factors, show that chronic noise exposure is consistently and reliably associated with cognitive impairments in school children.[3–5,7–9,22]

In the 1970s, the first well-designed naturalistic field study was conducted by Cohen et al.[22] who studied elementary school children living in four 32-floor apartment buildings that were located on an expressway. The sample of 73 children were tested for auditory discrimination and reading level. Children living on lower floors of the 32-story buildings (i.e. higher noise levels) showed greater impairment of auditory discrimination and reading achievement than children living in higher-floor apartments. Bronzaft and McCarthy[21] compared reading scores of elementary school children who were taught

in classes on a noisy side of a school near a railway line with the scores of the school children in classes on the quiet side of the same school. They found that children on the noisy side of the school building had poorer performance on the school achievement tests than those in classes on the quiet side of the school. The mean reading age of children in the classes on the noisy side of the school was three to four months behind the children in the quiet classes. A strength of these results is that they cannot be attributed to self-selection, a methodological problem found in many field studies, because the noise effects were found in the same school. Children were not assigned in any systematic manner to classrooms on the noisy or quiet side of the school.

In the 1980s, impaired performance on a difficult cognitive task was found in primary school children aged 8-9 years in a systematic well-controlled naturalistic field study around Los Angeles Airport (cross sectional results[3] longitudinal results[4]). Cohen and colleagues [3] concluded that their results were strikingly similar to those reported in the laboratory setting, but that replication was required before definitive conclusions could be reached. In the 1990s, these effects were confirmed around Heathrow Airport in a repeated measures field study comparing the cognitive performance and stress responses of children aged 9-10 attending four schools exposed to high levels of aircraft noise (>66 dB(A) 16hr Leq) with children attending four matched control schools exposed to lower levels of aircraft noise (<57 dB(A) 16hr Leq). Children tested at baseline were re-tested a year later at follow-up. The results indicated that chronic exposure to aircraft noise was associated with impaired reading comprehension and sustained attention after adjustment for age, main language spoken at home and household deprivation.[7] The within subjects analyses adjusting follow-up performance for baseline performance indicate that children's development in reading comprehension may be adversely affected by chronic aircraft noise exposure[8].

The results of a multi-level modelling study analysing pre-existing national standardised scores of school performance in relation to aircraft noise around Heathrow airport for 11,000 scores of children aged 11 suggest that aircraft noise is associated with school performance in reading and mathematics in a dose-response function but that this association is influenced by socio-economic factors.[24] These results replicate an earlier study examining standardised school performance scores conducted around New York City airports.[23]

Intervention Studies

Stronger evidence to suggest the existence of noise effects comes from intervention studies and natural experiments where changes in noise exposure are shown to be accompanied by changes in health and cognitive performance. To date, there have been three studies examining the effects of noise reduction on children's cognition: two intervention studies[4,20] with methodological flaws that limit their generalisability and one well-designed natural experiment; The Munich Airport Study.[5,6,29] The most convincing evidence for noise related cognitive effects came from the prospective longitudinal natural experimental field research around Munich Airport in older children with a mean age of 10.8 years (cross-sectional results[5] and longitudinal results[5,6,29]). In 1992 the old Munich airport closed and a new airport was opened. The cross-sectional results indicate an association between high noise exposure and poor long term memory and reading comprehension[5]. Longitudinal analyses, after three waves of testing, indicate improvements in long term memory and reading after closure of the old airport. Strikingly, these effects were paralleled by impairment of the same cognitive skills after the new airport opened.[29] The Munich Airport Study, designed as a prospective longitudinal natural experiment with a change in noise exposure, provides very strong evidence for the effects of aircraft noise on child health and cognition.

Chronic exposure to aircraft noise has also been associated with decreased motivation in school children[3–5,12] although the results are not consistent.[7] This motivation effect may either be independent or secondary to noise related cognitive impairments.

Noise annoyance

Children have been found to be annoyed by chronic environmental noise exposure.[5,7–9,21] In Munich, it was found that children living in noisier areas were significantly more annoyed by noise in their community as indexed by a calibrated community measure that adjusts for individual differences in rating criteria for annoyance judgements.[5] In London, noise annoyance was measured with child adapted standard self-report questions.[7–9,39] The repeated measures analyses from the Heathrow study indicate that children's annoyance remains constant over a period of a year with no strong evidence of habituation[8]. It is important to recognise that even young children report disturbance by environmental noise. In many ways child noise annoyance may be less subject to bias because children are less affected by other factors that influence annoyance in adult samples, namely: political and environmental attitudes.

Child Mental Health and Well-being

Noise exposure has consistently been associated with lower psychological well-being[5,6,8] in children. However, noise exposure does not seem to be associated with anxiety, depression and psychological morbidity or sleep disturbance.[7]

Previous research suggests that noise does not influence child mental health, however it may affect child stress responses and sense of well-being. Generally there are very few studies that have examined the effects of noise on child mental health. In one British study, the depression (Child Depression inventory) and anxiety (Child Manifest Anxiety Scale) scores of 169 children attending four schools exposed to high levels of aircraft noise (>66 dB(A) 16hr outdoor Leq) were compared with 171 children attending four matched control schools exposed to lower levels of aircraft noise (<57 dB(A) 16hr outdoor Leq) around Heathrow Airport in West London.[7] Mirroring the results from the adult studies, no associations were found between chronic aircraft noise exposure and anxiety and depression in school children. These results suggest that chronic aircraft noise exposure does not

directly affect anxiety and depression. However, it is possible that noise might affect other more stress-related aspects of mental health such as self-reported stress, social functioning, behavioural adjustment and well-being in children. This possibility is supported by evidence from the Munich Airport Study where it was found that aircraft noise was associated with reduced quality of life (measured by the Kindl) in children aged 9–11 years.[6]

'Quality of life' impairment is a different, less severe impairment than mental ill-health. In the West London Schools Study chronic aircraft noise exposure was weakly associated with overall psychological morbidity and specifically hyperactivity measured by the Strengths and Difficulties Questionnaire.[8] As this was an isolated finding, not found in the earlier Schools Health and Environment Study, it needs further research to confirm or refute this finding. A recent Austrian study has found that exposure to road and rail traffic noise was associated with poorer classroom behaviour and poor self reported child mental health derived from the Kindl Quality of Life Scale.[40] However, ambient noise was only associated with poorer mental health in children with low birth weight or pre-term birth and these conditions may have an effect independently from noise on mental health. These studies suggest that overall noise is probably not associated with serious disturbance of child mental health, however it may affect child stress responses and sense of well-being and there is a need for further research.

Physiological stress responses

There is evidence that children are not only susceptible to cognitive impairment in noisy environments but may also react physiologically to noise. Previous research has demonstrated a pattern of physiological and psychological stress responses associated with chronic noise exposure in children. Catecholamine (adrenaline and noradrenaline) secretion is commonly measured in noise studies as a physiological marke of chronic stress[5,6,9] There is moderate evidence that chronic noise exposure affects blood pressure and catecholamine hormone secretion. Chronic high levels of noise exposure have been associated with: higher levels of systolic and diastolic blood pressure[3,5,6,41,42] raised catecholamine secretion.[5,6] The effects on blood pressure[11] and catecholamine secretion[9,41] have not always been consistently demonstrated.

Summary

Table 1 below contains a summary of the strength of the effects of noise on child health. The categories of evidence have been classified into:

1) Sufficient evidence, that is consistent strong associations from high quality studies
2) Limited or weak evidence but it is possible there is an effect (e.g weak association in a few studies)
3) Inconclusive evidence where there are conflicting results.
4) No effect (that is negative association found in a few studies)
5) Inadequate evidence — that is it has not been thoroughly tested if at all

Table 1 Strength of the evidence for effects of environmental noise on children

Health Outcome	Strength of Evidence
Annoyance	Sufficient
Cognitive performance	Sufficient
Motivation	Sufficient/Limited
Wellbeing/Perceived stress	Sufficient/Limited
Catecholamine secretion	Limited/Inconclusive
Hypertension	Limited (weak associations)
Psychiatric disorder	Inconclusive/No effect
Sleep disturbance	Inadequate/No effect
Birth weight	Inadequate
Immune effects	Inadequate

* Cognitive performance has been measured as: reading, memory, auditory discrimination, speech perception, academic performance and attention.

3. KEY ISSUES TO BE CONSIDERED

Three key issues need to be taken into consideration when making suggestions for future research.

Possible Mechanisms of Noise Effects

The research evidence outlined above leaves us with the critical question of how does one explain the link between chronic exposure to noise and these adverse effects on child cognition and health? The theoretical understanding of child noise effects is very limited. The 'cognitive coping strategies' is the major theoretical psychological model of environmental stress that has been applied to explain the effects of noise on child performance and health.[12] Noise in the home or school environment is an environmental stressor that causes increased distraction, which may overburden developing cognitive systems. Children may adapt to noise interference during activities by filtering out the unwanted noise stimuli. This tuning out strategy may over-generalise to all situations when noise is not present, such that children tune out stimuli indiscriminately. Under some circumstances, these strategies may be detrimental and it is possible that the impairments in attention, auditory discrimination and/or speech perception may mediate the association between noise and child cognitive performance. Only four studies[7,8,10,22] have actually tested the mediating role of a hypothesised factor. The results from these studies provide empirical evidence that the effects of noise on child reading are more likely to be mediated by psycholinguistic processes such as auditory discrimination or speech perception. However, this is yet to be confirmed because the most recently published results suggest that the poorer reading was not mediated by speech perception and that impaired recall was in part mediated by reading.[29] There is evidence that noise related reading effects are not mediated by either annoyance[7] or sustained attention[8] or sound perception.[10]

Teacher frustration and communication difficulties could also be mechanism for cognitive and motivation effects.[13] Learned Helplessness has been proposed as a mechanism to account for the motivation effects.[1,3,5] The mechanism to account for the effects of noise exposure on children's blood pressure, endocrine disturbance and annoyance is considered to be the same stress mechanism proposed to account for the adult noise effects.[43]

Dose response relationships

Without robust dose-response curves the current state of knowledge can only provide a suggestive evidence base for guidance on the noise threshold level before effects become manifest. In the absence of these data it is difficult to give precise figures on how many children are taught in schools with noise levels that may adversely affect their health or set limits for noise exposure levels. This question will be addressed in the RANCH project (Road traffic and aircraft noise exposure and children's cognition and health: exposure-effect relationships and combined effects) funded by the European Commission (**www.ranchproject.org**). One of the main aims of the RANCH study is to determine exposure-effect relationships in children between chronic exposure to noise and impaired cognitive function, health, noise annoyance and sleep quality for aircraft, road traffic and combined sources. The RANCH study involves four epidemiological field studies on chronic noise exposure, including two smaller quasi-experimental psychological field studies on a limited sample of children, and two biomedical laboratory studies on acute noise exposure conducted within four countries across Europe. RANCH began in January 2001 and is planned to take three years to complete at the end of 2003.

Vulnerable Child Groups and Individual Differences

Although there are overall trends showing that chronic exposure to noise is associated with impaired cognition over a range of functions, there may be individual differences in these effects. Some children in the population may be more vulnerable to noise effects than others. There is limited evidence that children who have lower aptitude[12,44,27] or other difficulties such as learning difficulties[45,46] may be more vulnerable to the harmful effects of noise on cognitive performance. There may also be individual differences according to age and gender.

4. SUMMARY AND CONCLUSIONS

To conclude, there is sufficient evidence to suggest that chronic noise exposure at schools affects child health and performance. Since research results are consistent, it may be wise to apply the precautionary principle of environmental law for improving the school environment around airports and transport developments using the recommended WHO noise levels as guidelines.[47] To date, the potential negative and positive effects of interventions have not been thoroughly researched enough to provide policy makers with clear guidance. The development of future interventions and policies must be concurrent with a thorough research evaluation to determine the efficacy of the intervention to reduce exposure and reduce the adverse health effects of noise on children.

There is a need to evaluate a) sound insulation programmes and b) policies to reduce noise exposure in a well controlled large scale study to determine the impact of these programmes on a range of performance and health effects associated with child noise exposure. Future studies need to evaluate the protective and restorative effects of accessibility to quiet zones (or options for protection of such quiet zones i.e. natural areas, parks, etc.) on child health. Studies are required to provide a more precise insight into the mechanisms that underlie child noise effects. The identification of vulnerable subgroups within the child population should also be a research priority.

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