The effects of environmental noise on school children : summary of effects and review of intervention studies

Les effets du bruit en milieu scolaire sur les enfants : présentation des études en cours

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There is consistent research evidence that chronic exposure to environmental noise leads to impaired cognitive function and health in children. In this review article we will briefly summarise the non-auditory health effects of noise on children and provide a review of the current research evidence of interventions to reduce the impact of noise on child health and performance. In studies examining the effects of chronic aircraft, rail and road traffic noise on children there is consistent evidence that noise exposure adverse effects 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 little evidence that chronic noise exposure affects child mental health and sleep disturbance. Given that it there is broad consensus that there is sufficient evidence that noise exposure has adverse effects on child health [1,2], results from intervention studies are important because they can provide an evidence base to inform policies and measures to protect children from the adverse effects of noise. The literature on intervention studies is sparse and research produced is of varying quality. To date, the potential negative and positive effects of interventions have not been thoroughly researched enough to provide policy makers with clear guidance. Subject to evaluation, the following interventions might however be beneficial for child health : sound insulation and noise abatement programmes in schools and polices to reduce noise at source.

There is a need to evaluate :

- sound insulation programmes
- policies to reduce noise exposure in a well controlled large scale studies to determine the impact of these programmes on a range of performance and health effects associated with child noise exposure.

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.

Il existe une corrélation évidente entre les différentes recherches sur le fait que l'exposition chronique à un environnement bruyant amène à affaiblir les fonctions cognitives et la santé des enfants. Dans cette revue bibliographique, nous allons rapidement résumer les effets non-auditifs du bruit sur la santé des enfants et présenter une revue des recherches en cours témoignant des actions pour réduire l'impact du bruit sur la santé et sur les performances des enfants. Dans les études examinant les effets chroniques des trafics routier, ferroviaire et aérien sur les enfants, il y a un témoignage cohérent sur le fait que l'exposition au bruit est contraire aux performances cognitives des enfants et qu'elle est associée à la gêne due au bruit et à la dégradation du confort. Il est moins évident que l'exposition chronique au bruit affecte la santé mentale des enfants et gêne le sommeil. Ceci étant dit, il y a un large consensus pour dire que l'exposition au bruit a un effet contraire sur la santé des enfants [1,2]. Les résultats venant d'études intermédiaires sont importants parce qu'ils peuvent fournir une base claire pour orienter les politiques et les mesures nécessaires pour protéger les enfants des effets nocifs du bruit. La littérature sur ces études intermédiaires est clairsemée et les recherches produites de qualité variable. À l'heure actuelle, les effets potentiellement positifs ou négatifs des interventions n'ont pas été entièrement explorés pour fournir aux législateurs des guides clairs. Sujettes à évaluation, les actions suivantes devraient être bénéfiques pour la santé des enfants : l'isolation acoustique et les programmes de réduction du bruit dans les écoles et des textes pour réduire le bruit à la source.

Il y a un besoin d'évaluer :

- Les programmes d'isolation acoustique,
- Les textes pour réduire l'exposition au bruit au sein d'études à grande échelle bien contrôlées afin de déterminer l'impact de ces programmes sur une série d'effets sur la santé et la performance associée à l'exposition des enfants au bruit.

Des études sont demandées pour fournir une vision plus précise des mécanismes que soustendent les effets du bruit sur les enfants. L'identification de sous-groupes vulnérables à l'intérieur de la population infantile devra aussi être une priorité de recherche.

There is consistent research evidence that chronic exposure to environmental noise leads to impaired cognitive function and health in children [3, 4, 5]. Impairments of early childhood development and education by environmental pollutants such as noise, may have life long effects on achieving academic potential and health [6]. In this review article we will briefly summarise the non-auditory health effects of noise on children (for more detailed discussion see 7 and 8) in Section I. Given that most review articles suggest that the next stage for research is to conduct intervention studies, in Section II we provide a review of the current research evidence of interventions to reduce the impact of noise on child health and performance. In the final Section III we provide a summary and conclusions that with a strong emphasis on requirements for future research in the light of identified key research issues.

Summary of the non-auditory health effects of noise on children (Section I)

In studies examining the effects of chronic aircraft, rail and road traffic noise on school children's cognitive performance and health the following results have been found in children exposed to high levels of environmental noise in relation to : a- cognitive performance and b) physiological and psychological stress responses.

Cognitive performance

The most widespread effects of noise found in children are cognitive impairments, though these effects are not uniform across all cognitive tasks [9, 10]. There is empirical evidence from laboratory [11, 12, 13, 14] and field studies [13,14] 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 [7,15].

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

- poorer reading ability and school performance on national standardised tests [16, 17, 18, 19, 20, 21, 22, 23, 24, 13, 25]
- poorer memory that requires high processing demands of semantic material [26, 13, 14, 9, 27, 28, 29]
- deficits in sustained attention and visual attention [30, 31, 32, 33, 34, 35, 36, 29, 30]
- poorer auditory discrimination and speech perception [18, 31, 7, 36, 13, 25]

Chronic exposure to aircraft noise has also been associated with decreased motivation in school children [31, 37, 7, 13] although the results are not consistent [20]. This motivation effect may either be independent or secondary to noise related cognitive impairments.

Physiological and psychological 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. 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 [31, 13, 14, 38, 39] ; raised catecholamine secretion [13, 14]. The effects on blood pressure [40] and catecholamine secretion [38, 39] have not always been consistently demonstrated.

Noise exposure has consistently been associated with raised annoyance [17, 13, 20, 30, 39] and lower psychological well-being [13, 14, 30] in children.
A 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 [30]. However, noise exposure does not seem to be associated with anxiety, depression and psychological morbidity or sleep disturbance [20]. Previous research suggests that noise does not influence child mental health, however it may affect child stress responses and sense of well-being.

Key Issues

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 [7], see Figure 1.
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 [18, 25, 20, 30] 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. There is evidence that noise related reading effects are not mediated by either annoyance [20] or sustained attention [30] or sound perception [25].

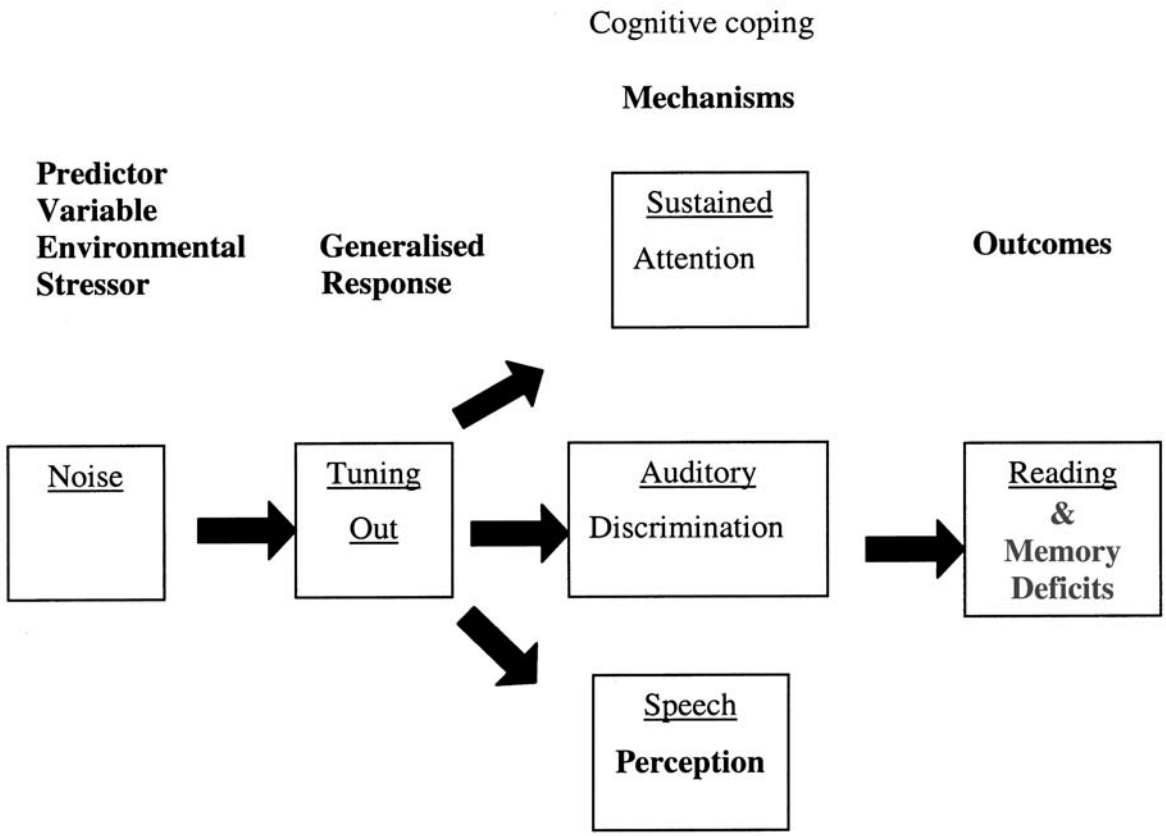

Fig. 1 : A summary of the Mechanisms to Account for Noise Related Cognitive Deficits

Teacher frustration and communication difficulties could also be mechanism for cognitive and motivation effects [6]. Learned Helplessness has been proposed as a mechanism to account for the motivation effects [31, 3, 13]. 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.

Dose response relationships

Without robust dose-response curves the current state of knowledge can not provide a clear guidance on the 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 effect thier health or set limits for noise exposure levels. This question will be addressed in the RANCH project (Road traffic and aircraft noise exposue and children's cognition and healrh : exposure-efect relation ships and combined effects) funded by the European commission (www.ranchproject.org).

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 [7, 40, 24] or other difficulties such as learning difficulties [41, 42] may be more vulnerable to the harmful effects of noise on cognitive performance. There may also be individual differences according to age and gender.

Review of the research evidence of interventions to reduce the impact of noise on child health and performance (Section II)

Compared with evidence from cross-sectional studies or anecdotal reports, intervention studies or natural experiments provide stronger empirical evidence for child noise effects. Given that it there is broad consensus that there is sufficient evidence that noise exposure has adverse effects on child health [1, 2]. results from intervention studies are important because they can provide an evidence base to inform policies and measures to protect children from the adverse effects of noise. The literature on intervention studies is sparse and research produced is of varying quality. In order to provide an evidence base to support policy and planning, an evaluation of intervention studies will be presented in the following section.

An intervention study or natural experiment is designed to test whether a change in noise exposure is accompanied by a change in health or performance (both improvements or impairments). Both internal and external noise sources can contribute to total noise exposure in schools. Interventions to reduce internal noise generated due to a poor acoustical environment largely involve acoustical

treatments of classrooms (e.g sound absorbent ceiling tile or wall panels) to reduce total noise levels. The level of external environmental noise sources, such as aircraft, road traffic and railway, that contribute to classroom noise levels can also be reduced by classroom acoustical treatments. In addition to these structural interventions, external noise sources associated with transportation can also be reduced by planning (e.g airport terminals, roads, siting of new schools) and regulation of noise sources (e.g transportation limits set). These types of interventions reducing external noise levels at source can potentially have a wide ranging impact on the total school environments because noise exposure is not only reduced in classrooms but also in playgrounds and other learning spaces in the schools (halls and gymnasium etc). See Table 1 for a summary of the six studies reviewed below.

Study Number and Reference	Design	Sample	Intervention	Change in exposure	Health outcomes	Change in health outcomes
Bronzaft (1981)	Field Survey.	N=350 second, third, fifth and sixth graders in 1978 And N=605 third, fourth, fifth and sixth graders N=10 teachers	One inch thick butyl- rubber pads on the rail tracks closest to the school and sound absorbent ceilings	Total decrease of 6-8 dB(A) 89dB(A) (average) before installation of pads noise, levels were 85-86 dB(A) after. Further decrease due to ceiling intervention noise levels was reduced to 81-83 dB(A).	Differences in teaching methods California Achievement Test.	Reduced perceived noise. Reduced volume of teachers voice. Improved reading ability compared to Bronzaft (1975)
Cohen et al (1981)	Longitudinal and cross sectional field survey	N=135 third and fourth grade students.	Noise abatement in a number of classrooms.	7 dB(A) reduction Noisy classrooms were 70, 29 dB(A) Leq (mean), abated classroom 62, 82 dB(A) Leq (mean)	Blood pressure Health Helplessness Distractibility Reading Maths	Small ameliorative effects on motivation and mathematics. No effect on reading score General lack of effects of noise abatement
Evans *et al* (1995, 1998) Hygge, 2001	Prospective longitudinal natural experiment with a change in noise exposure	Total 326 (range 8 –12 years) Old airport N= 43 (control) N=65 (exposed) (mean age = 10, 78) New Airport N= 107(control) N=111(exposed)	Relocation of airport	Old airport from 68 – 54 24h dB(A) Leq Decrease of 14 dB(A) Leq New Airport From 53- 62 24h dB(A) Leq Increase of 9 dB(A) Leq	Attention Memory Reading Motivation Annoyance Quality of Life Blood pressure Catecholamines Cortisol	The results indicate improvements in long term memory recall task and the reading test (only significant for the difficult sections), lower rates of systolic blood pressure and catecholamine secretion after the closure of the old airport. Strikingly, these effects were paralleled by impairment of the same cognitive skills and increased levels of psychophysiological stress indicators after the new airport opened.
MacKenzie and Airey (1999)	Field survey	N=126 Teachers or primary aged children. Pupils attending the school	Acoustic tiles.	Background noise reduced 7-9 dB(A) Measured average background levels for untreated classrooms when the pupils were silent were 55, 5 dB(A) compared with 46, 5 dB(A) in the treated classroom. Measured average background levels for untreated classrooms when the pupils were working were 77, 3 dB(A) compared with 70, 1 dB(A) in the treated classroom.	Psychological effect of excessive classroom noise on teachers Psychological effect of excessive classroom noise on pupils Speech intelligibility Word intelligibility	Children in acoustically treated classrooms have: Improved speech intelligibility Improved word intelligibility
Maxwell & Evans, 1998, 2000	Natural experiment using a cohort design	Total: 90 Age range 3-4 years N=48 in years (quiet condition) N=42 in year 2 (noisy condition)	Installation of sound absorbent panels in classroom ceiling of a preschool	5 dB(A) reduction (average decibel level) In year 1 before the intervention the average decibel level was: 75, 92 dB(A) Leq. In Year 2 after the intervention the average decibel level was: 70,90 dB(A) Leq.	Pre-reading language skills (number, letter, word recognition) Motivation Rhyming task Teacher reports	The children performed better in the quieter condition on prereading skills (number, letter and simple word recognition) and on a motivation task than in the noise condition. There was no difference in rhyming or letter-to-sound performance across noise conditions. Classroom teachers rated children in the quiet condition as having better language skills.
Caric and Cudina 2001	Field survey	N=271 Pupils Aged 3-8 years 33 teachers	Various engineering, administrative and behavioural interventions were applied to the school. These included: replacing windows, change in the traffic regime of the local area, traffic claming, insulation in the gymnasium and dining hall, changing the school schedule, relocating the classrooms and reducing open planned classrooms.	Not reported	Noise survey Opinion poll of teachers and pupils	Younger ages pupils reported greater noise disturbance before the interventions were applied and after the interventions rated the improvements more highly than the older age group of pupils.

Table 1 : Summary Table of Six Intervention Studies

Interventions and natural experiments to reduce external environmental noise

To date, there have been three studies examining the effects of noise reduction on children's cognition : two intervention studies [16, 37] with some methodological issues that may limit their generalisability and one well-designed natural experiment [13, 14, 27]. Bronzaft (1981) found that following attenuation in rail noise previous significant differences [17] in reading achievement were removed between children from classrooms close to elevated train tracks and children on the opposite side of the building. Noise was lowered by acoustical treatment of classrooms and by one-inch thick butyl-rubber pads on the rail tracks closest to the school (6-8 dBA reduction in total). Teacher self-reports showed that they did notice a huge reduction in noise interference. Cohen and colleagues (1981) found that noise abatement in classrooms (7 dBA reduction) had small ameliorative effects on motivation and mathematics, but not on reading. These intervention studies [16, 37] had certain limitations : no comparisons of reading ability before and after noise reduction ;

no objective measure of actual noise reduction ; and insufficient sample sizes which makes the potential for selection bias more likely. The Munich Airport Study provides the best evidence that a reduction in noise level of only one-year duration reduces noise-induced cognitive impairments [27], but further intervention studies are needed to test practical and affordable interventions, such as insulating classrooms against noise exposure in areas where external noise levels are unlikely to change. The Munich study suggests that for noise effects to be reversed in children, noise exposure needs to be reduced by at least 10 dBA Leq and that it takes at least one year of being taught in a quieter classroom before health or performance gain can be observed.

Interventions to reduce internal classroom noise

The three studies evaluating interventions to reduce internal noise in classrooms provide preliminary evidence that noise reduction can lead to improved performance [43, 44, 45]. Mackenzie and Airey (1999) in a field survey in primary schools before and after acoustic tiles were applied to one classroom found that background noise was reduced by 7-9 dBA Leq and that children in acoustically treated classrooms have improved speech intelligibility (words being understood) and improved word intelligibility (word recognition). Maxwell and Evans (1998) examined the impact of acoustical renovation of a day care centre on preschool aged children's (4 years) cognitive performance in a natural experiment using a cohort model design. Cognitive measures of two different samples of children and noise exposure assessment were taken in the same classroom at baseline (the noisy condition) and a year later (the quiet condition) after the installation of sound absorbent panels in the classroom ceilings. The installation of sound absorbent panels reduced noise by 5 dBA (average decibel level).
The children performed better in the quieter condition on pre-reading skills (number, letter and simple word recognition) language skills and at motivation tasks than in the noise condition. There was no difference in rhyming or letter-to-sound performance across noise condition. Classroom teachers rated children in the quiet condition as having better language skills. Caric and Cudina (2001) conducted a survey and opinion poll of children and teachers attending primary school in Slovenia near a busy road a before and after various engineering, administrative and behavioural interventions were applied to reduce the noise levels. Preliminary results suggest that the interventions reduced noise levels (the actual levels were not reported). There were fewer complaints about the school from the pupils after the interventions. Test performance on annual school tests improved by 10 percent after the interventions. This study demonstrates that interventions do not have to be costly or elaborate for noise reduction to have benefits.

The strength of the evidence from these studies is limited by the fact that the performance comparison was between different cohorts of children attending the same school. A between cohort comparison is less sensitive than a within subjects comparison because other differences between the samples (e.g IQ, SES, ethnicity) might confound the results and this is especially likely with small sample sizes.

Key Issues

Three key issues need to be taken into consideration when making recommendations about the nature of interventions to reduce noise effects. These issues are :
- Length of exposure before the onset or offset of health effects. It is still unknown how long it takes for these effects to be reversed if there is a reduction in noise exposure.
- By what level should noise exposure be reduced to before health gain is observed ?
- Interventions can be costly and reducing noise at source can be very difficult which raises the question of whether there are other interventions that may be effective in preventing noise effects in children apart from noise reduction ?

Summary and Conclusions (Section III)

In this article the research evidence for non-auditory health effects of noise on children has been summarised and the evidence from intervention studies reviewed. The interventions assessed have included : acoustical treatment of classrooms, relocation of airports, and reduction of railway noise at source. 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 [1]. To date, the potential negative and positive effects of interventions have not been thoroughly researched enough to provide policy makers with clear guidance.
Subject to evaluation, the following interventions might however be beneficial for child health : sound insulation and noise abatement programmes in schools, polices to reduce noise at source, organisation of classrooms within schools so that learning environments are placed in the quietest sections of schools, arrange the timetable so that literacy classes are held in quiet times during the day, educational interventions to provide extra classes for most affected cognitive functions. The development of these 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.

Future Research

There is a need to evaluate : sound insulation programmes and the 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 of the possibility of keeping open 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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