FINAL REPORT

West London Schools Study

Aircraft noise at school and children's cognitive performance and stress responses

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Jointly Funded by: Department of Health and the Department of the Environment, Transport and the Regions

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EXECUTIVE SUMMARY

Background and Aim

Previous research suggests that children may be a high risk group vulnerable to the effects of noise (Cohen *et al.,* 1980, Evans & Lepore, 1993, Evans *et al.,* 1995, Evans & Maxwell, 1997, Haines *et al.,* in press a, and b; Stansfeld *et al.,* 2000). Previous field studies have not been of sufficient size to account adequately for the role of confounding factors in the relationship between noise and cognitive impairments nor have they examined the possibility that some children may be more vulnerable to the effects of noise than others (Cohen et al., 1980; Evans *et al.,* 1995, 1998; Evans & Maxwell, 1997, Haines *et al.,* in press a, in press b). The broad objective of this study is to test whether the noise effects previously found in children are attributable to aircraft noise exposure, after adjustment for confounding factors both at the school and individual level, and to examine whether children exposed to high levels of social disadvantage are at greater risk of noise effects. The specific aim of this study is to confirm that chronic high levels of aircraft noise exposure in children are associated with: a) cognitive impairments (in reading, memory and attention); and b) stress responses (catecholamine secretion, noise annoyance and self reported stress) after adjustment for potential confounding factors at the school and individual level.

Study Design and Methods

The cognitive performance and stress of children attending 10 primary schools exposed to high levels of aircraft noise were compared cross-sectionally with 10 matched control schools exposed to lower levels of aircraft noise around Heathrow Airport in West London. The schools were drawn from areas around Heathrow Airport that differed in social deprivation. Schools were chosen such that children were matched across high and low aircraft noise by: age; sex; and sound level at the school from non aircraft sources; existing noise protection in the schools; socio-economic status; and ethnicity of the school population. Children were already randomly selected into mixed-ability classes and schools were randomly selected for testing days. The cognitive tests and questionnaires were group administered in the classroom, controlling for time of day across noise exposure. Teachers and parents of all children were given a questionnaire to complete. Noise measurements were carried out at the time of cognitive testing to assess school noise exposure. An overnight urinary sample was collected from a sub-sample of the children to measure catecholamines.

Results

The results of this study confirm the results from previous studies since noise exposure was associated with impaired reading and raised annoyance. There was no variation in the size of the noise effects in vulnerable sub-groups of children. The results of this study do not confirm all aspects of previous studies because high levels of noise exposure were not associated with impairments in memory and attention, nor raised catecholamine secretion or self-reported stress. These are the 6 main findings:

1) Aircraft noise exposure was associated with poorer reading performance on difficult items after adjustment for age, main language spoken and social deprivation at the individual and school level. Aircraft noise was not associated with poorer performance on memory, sustained attention or overall reading score.

2) Aircraft noise exposure was associated with raised annoyance after adjustment for age, main language spoken and social deprivation at the individual and school level.

3) Aircraft noise was weakly associated with hyperactivity and psychological morbidity after adjustment for age, main language spoken and social deprivation at the individual and school level.

4) Aircraft noise was not associated with perceived stress, stressful life events, nor raised catecholamine or cortisol secretion.

5) There was no evidence that noise effects were larger in vulnerable child groups, specifically those from areas of high social disadvantage and those with English as an additional language.

6) In parents and teachers, aircraft noise exposure was associated with annoyance. In parents and teachers, aircraft noise was not associated with poorer general health or perceived stress.

Conclusions

The cognitive results from this study provide new evidence concerning the nature of cognitive noise effects. The results indicate that chronic aircraft noise exposure does not always lead to generalised cognitive effects but, rather, more selective cognitive impairments in children exposed to chronically high levels of noise exposure (Cohen et al., 1986; Evans et al., 1995; Evans & Cohen, 1987; Wachs & Gruen, 1982). The noise effect on reading confirms previous studies (Evans & Lepore, 1993; Evans et al., 1995, Evans and Maxwell, 1997; Haines et al., in press a and b) that noise exposure is associated with poorer reading performance but that the effects are confined to difficult items and not on simple items. Taking the annoyance results of this study together with previous studies in children and adults, it can be concluded that chronic noise exposure is associated with raised noise annoyance in children.

Policy Recommendations and Future Research

These results add to the growing research evidence around international airports that chronic high levels of noise exposure affect children's reading and lead to raised annoyance. These result suggest that children in Britain exposed to high levels of aircraft noise at school are being taught in a disadvantaged learning environment that has negative consequences for cognitive development and well-being. These results should be considered when making policy on noise exposure limits, school environments and buildings and when planning future transport developments. The next step for future research is to test for dose-effect relationships between transport noise and children's health and cognitive function.

1. INTRODUCTION

Previous research suggests that children may be a high risk group vulnerable to the effects of noise (Cohen *et al.,* 1980, Evans & Lepore, 1993, Evans *et al.,* 1995, Evans & Maxwell, 1997, Haines *et al.,* in press a, in press b; Stansfeld *et al.,* 2000). However, previous field studies have not been of sufficient size to account adequately for the role of confounding factors in the relationship between noise and cognitive impairments, nor have they examined the possibility that some children may be more vulnerable to the effects of noise than others (Cohen et al., 1980; Evans *et al.,* 1995, 1998; Evans & Maxwell, 1997, Haines *et al.,* in press a, in press b). The objective of this study is to test whether the noise effects previously found in children are attributable to aircraft noise exposure, after adjustment for confounding factors both at the school and individual level, and to examine whether children exposed to high levels of social disadvantage are at greater risk of noise effects.

Background and Rationale

Chronic exposure to aircraft noise, rather than the less intrusive rail and road traffic noise, has been most studied for its effects on children. This is appropriate as aircraft noise in the vicinity of airports is more intense, more unpredictable and more difficult to mask than road or rail traffic noise. The most striking and widely researched effects of noise found in children are cognitive impairments, though these effects are not uniform across all cognitive tasks (Cohen et al., 1986; Evans & Lepore, 1993). 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 (Cohen et al., 1986; Evans et al., 1995; Evans & Lepore, 1993; Hygge, 1994). There is empirical evidence from experimental laboratory studies in adults (Smith & Broadbent, 1992; Smith & Jones, 1992) and children (Enmarker *et al.,* 1998; Hygge, 1994; Meis *et al.,* 1998) and from the Munich Airport Field Study (Evans et al., 1995, 1998) for these divergent noise effects across cognitive tasks of varied difficulty. The general finding is that when performance on simple and complex tasks are examined in noise, only performance on the complex tasks is affected by noise exposure (Stansfeld et al., 2000) and this effect has been explained by arousal and attention theory (Smith & Jones, 1992).

Apart from the cognitive effects, previous research has demonstrated a pattern of physiological and psychological stress responses associated with chronic noise exposure in children. There is empirical evidence for the arousal mechanism in the correlational evidence that children chronically exposed to noise have higher levels of physiological stress, such as systolic and diastolic blood pressure (Cohen *et al.*, 1980; Evans *et al.*, 1995; Evans *et al.*, 1998; Regecova & Kellerova, 1995) and catecholamine secretion (Evans *et al.*, 1995; Evans *et al.*, 1998).

The most widespread and well documented subjective response to noise is annoyance and children have been consistently found to be annoyed by chronic aircraft noise exposure (Bronzaft & McCarthy, 1975; Evans et al., 1995; Haines et al in press a, in press b). This can be interpreted as a chronic affective response, indicating impaired well-being. This is supported by evidence that noise exposure has also been associated with reduced psychological well-being (Evans et al., 1995); lower self-reported quality of life (Evans et al., 1998); and higher levels of self-reported stress (Haines et al., in press b). However, noise exposure does not seem to be associated with anxiety, depression or psychological morbidity, as measured by the Strengths and Difficulties Questionnaire (Goodman, 1994, Haines et al, in press a). In this study, we aim to replicate the findings that noise exposure affects child noise annoyance, self-reported stress and catecholamine secretion, but that it does not influence child mental health.

There is still uncertainty as to how much the observed cognitive impairments can be attributed to noise effects because these cognitive tasks are also influenced by the quality of the school (school effects, Rutter, 1985) and the level of social deprivation of the area in which the children live. A multi-level modelling study around Heathrow airport suggests that chronic aircraft noise exposure is associated with school performance after adjustment for school effects, but that this association is influenced by socio-economic factors (Haines et al. 2000b). These results indicate that noise exposure and social class are inter-related and possibly might act together to influence performance.

Previous research has dealt with this inter-relationship through matching samples on social factors and making statistical adjustment for social factors. In this study, we plan to examine children with high levels of social disadvantage as a group who may be at higher risk within the child population. It is well known that social disadvantage is associated with low school achievement (Mortimore & Whitty, 1997). The effects of additional adverse environmental conditions such as noise may have a cumulative effect on low school achievement in children from socially disadvantaged backgrounds. Therefore, children from disadvantaged backgrounds may be more vulnerable to the effects of chronic noise exposure than more advantaged children. 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 that we will examine in other sub-groups of children, namely: boys and girls; high and low school achievers; white and non-white children; English as the main language spoken at home and non-English as the main language spoken at home. These stratified analyses will help to identify vulnerable sub-groups within the child population.

Specific aim and hypotheses

The specific aim of this study is to confirm that chronic high levels of aircraft noise exposure in children are associated with: a) cognitive impairments (in reading, memory and attention); and b) stress responses (catecholamine secretion, noise annoyance and self reported stress), after adjustment for potential confounding factors at the school and individual level.

1) Chronic aircraft noise exposure produces cognitive impairments in reading comprehension, sustained attention and long term memory recall after adjustment for confounding factors. No effects are expected on the control cognitive outcomes: recognition and working memory. It is hypothesised that chronic noise exposure will have a larger effect on difficult cognitive tests compared with simple tests.

2) Chronic aircraft noise exposure in school children will be associated with higher levels of annoyance by noise than children in schools exposed to lower levels of aircraft noise after adjustment for confounding factors.

3) Chronic aircraft noise exposure in school children will be associated with higher levels of self-reported stress than children in schools exposed to lower levels of aircraft noise. No effects are expected on the mental health outcomes.

4) Chronic aircraft noise exposure in parents and teachers will be associated with higher levels of annoyance by noise and perceived stress than in parents and teachers exposed to lower levels of aircraft noise.

5) The effects of noise exposure on reading and annoyance will be larger in children from:

i) deprived households than children from non-deprived homes;

ii) children who have a Non-English language as the main language spoken at home compared with children who speak English at home;

2. METHOD

The methods for The West London Schools Study will be outlined in this section which is ordered into five main sections: 2.1) design; 2.2) sample; 2.3) selection and matching of schools; 2.4) materials; and 2.5) procedures.

2.1 Design

The cognitive performance and stress of children attending 10 primary schools exposed to high levels of aircraft noise were compared cross-sectionally with 10 matched control schools exposed to lower levels of aircraft noise around Heathrow Airport in West London. The schools were drawn from areas around Heathrow Airport that differed in social deprivation. Schools were chosen such that children were matched across high and low aircraft noise by: age; sex; sound level at the school from non aircraft sources; existing noise protection in the schools; socio-economic status; and ethnicity of the school population. Children were already randomly selected into mixed-ability classes and schools were randomly selected for testing days. The cognitive tests and questionnaires were group administered in the classroom controlling for time of day across noise exposure. Teachers and parents of all children were given a questionnaire to complete. Noise measurements were carried out at the time of cognitive testing to assess school noise exposure. An overnight urinary sample was collected from a sub-sample of the children to measure catecholamines.

2.2 Sample

The Sample

The children came from 20 co-education state primary schools that were chosen according to the noise exposure of the school area. The participants were 451 year four pupils (mean age = 8 years and 8 months). 236 attended schools in a high-aircraft noise-impact urban area (16-hr outdoor Leq > 63 dBA) and 215 attended schools in a low-aircraft noise-impact urban area (16-hr outdoor Leq < 57 dBA) surrounding Heathrow Airport in West London (Hounslow, Hillingdon and Slough). The participants were 229 boys (51%) and 222 girls (49%), 25 teachers and 361 parents.

The children from 20 schools were selected randomly in whole year 4 classes from all the year 4 classes at the school, that is the classes or the children were not selected according to academic achievement nor on a volunteer basis. The head teacher of each school was asked to choose a class which was representative of year 4 at the school. In two schools where there were not enough children in a whole class, the head teacher randomly selected 30 children from the total number of children at the school in year 4. None of the classes selected were streamed. In each selected class, every child was eligible to take part in the study and every child in the class was invited to take part. Catecholamines were measured in a random sub-sample of 204 children split between noise exposed (96) and control groups (108).

2.3 Selection and Matching of Schools and the Schools Selected

It was important that bias should not be introduced in the selection of schools. The methods used to select and match the schools and the schools selected to take part in the study will be outlined in detail in the three sections below: 2.3.1 the selection procedure; 2.3.2 the matching procedure; 2.3.3 the schools selected.

2.3.1 The selection procedure

The first step in the selection of schools was to decide which boroughs around Heathrow should be included. Initially, consideration was given to all the boroughs near Heathrow Airport. The ‘a priori’ criteria established for a borough to be considered was that the primary schools were exposed to a range of aircraft noise levels that included both 'high noise' (<63 dBA Leq) and 'low noise' (>57 dBA Leq) within that borough. This criteria to select both high and low noise exposed schools from the same boroughs around Heathrow Airport was established in order to minimise physical and social environmental differences, apart from noise, influencing the performance results.

A preliminary investigation was made of the range of aircraft noise exposure in those schools in the boroughs of: Hillingdon, Hounslow, Slough, Richmond, Spelthorne, Windsor and Maidenhead, Bracknell Forest, Newbury, Reading, Wokingham District and Staines. A list of all primary schools in the high aircraft noise exposure areas from these boroughs around Heathrow airport was obtained from the Local Authorities according to the 1994 16 hour Civil Aviation Authority Contours.

This investigation yielded the following results:

These boroughs had 21 schools exposed to > 63 dBA Leq:
Hounslow (N=17), Hillingdon (N=1), Windsor & Maidenhead (N=1) and Slough (N=2).

These boroughs had 11 schools exposed to > 66 dBA Leq:
Hounslow (N=9) and Slough (N=2).

These boroughs did not have any schools exposed to > 63 dBA Leq:
Richmond, Spelthorne, Bracknell Forest, Newbury, Reading, Wokingham District and Staines.

On the basis of this investigation a decision was taken that schools for this study should come from these boroughs: Hounslow, Hillingdon, Windsor & Maidenhead and Slough. This is because these boroughs had primary schools exposed to a range of aircraft noise levels that satisfied the ‘a priori’ criteria. The following boroughs were not considered for inclusion because none of the primary schools were exposed to levels of aircraft noise greater than 63 dBA Leq: Richmond (one school lay on the 63 LAeq contour), Spelthorne, Bracknell Forest, Newbury, Reading, Wokingham District and Staines.

The second step in the school selection procedure was to obtain 10 high noise exposure schools from the 20 or 21 high noise exposed schools that fulfilled our selection criteria.

Outright exclusion criteria

Schools exposed to high levels of aircraft noise were excluded in the first instance if they:

a) had no pupils in the age range 8-11 years;
b) were single sex schools;
c) were schools for children with special needs;
d) were non-Government schools;
e) were exposed to high levels of noise from non-aircraft environmental noise sources (road, rail and industrial noise). A school was excluded if the major source of environmental noise was road traffic, rail or industrial noise rather than aircraft noise exposure. This was determined by measuring distances to the schools from A-roads, B-roads and motorways by using maps and Geographic Information Systems software maps and site inspections of road traffic flow and actual exposure.

At this stage, out of 21 high noise exposed schools the following 5 schools were excluded: 4 church schools (1 Hounslow, 2 Windsor and Maidenhead, 1 Slough); and 1 special school (Hounslow). Furthermore, we did not consider the one Hillingdon school exposed to high levels of aircraft noise because it was only greater than 63 dBA. This left 15 schools to be considered for inclusion (Table 1).

Table 1: List of 15 High Noise Schools in Boroughs that were considered to take part in the study after exclusions

Hounslow High Noise Schools

High Noise School	**Type of School**	**Sound Insulation**
1. Marlborough >63	Govt	Complete
2. Springwell >63	Govt	None
3. Wellington >63	Govt	None
4. Worple >63	Govt	Complete
5. Andrew Ewing Junior >63	Govt	Complete
6. The Smallberry Green Primary >63	Govt	Complete
7. Chatsworth Junior >66	Govt	None
8. Bedfont Junior >66	Govt	None
9. Cranford >66	Govt	Complete
10. Hounslow Heath Junior >66	Govt	Partial
11. The Orchard >66	Govt	Partial
12. Grove Road >66	Govt	Partial
13. Beavers >66	Govt	Complete

Slough High Noise Schools

High Noise School	**Type of School**	**Sound Insulation**
14. Pippens School > 69 Dba Leq	Grant Maintained	Partial

Windsor & Maidenhead High Noise Schools

High Noise School	**Type of School**	**Sound Insulation**
15. Wraysbury Primary > 63 DbA Leq	Govt	Complete

Sound insulation

Consideration was also given to the fact that some of the high noise exposed schools would have a degree of sound insulation. Each of the schools was classified according to the extent to which they were sound insulated and were categorised as:

1) Completely double glazed/sound insulated;

2) Partially double glazed/sound insulated;

3) Not at all sound insulated.

These data were collected from the local authority property divisions within Education departments or by telephone survey. Of the remaining 15 high noise schools to be considered for inclusion: 7 were completely double glazed, 4 were partially glazed and 4 had no sound insulation at all.

Our criterion of no sound insulation at all was relaxed as only 4 schools would have met that criterion. Schools were excluded on the grounds of sound insulation when it was deemed that the level of sound insulation would not allow us to reliably detect a noise effect. This information was gathered by the local authorities in 10 schools (7 Hounslow, 2 Slough, 1 Windsor and Maidenhead) who completed a school sound insulation inspection sheet that was devised by the National Physical Laboratory (NPL) (Appendix 1). This inspection also involved conducting indoor noise measurements (Appendix 1, for protocol). These data were analysed by NPL and no school was ruled out on the grounds that sound insulation would not allow us to reliably detect a noise effect.

Site inspections

Site inspections of the 15 high noise schools were made by research staff (MH & MJ) and local authority officers in June and July 1999 (12 Hounslow; 2 Slough; 1 Windsor & Maidenhead). At the same time, site visits were also made of potential control schools (these will be discussed in the matching section below).

The High Noise Schools Initially Selected

The most suitable 11 high noise exposed schools were selected to be invited to take part in the study. In Hounslow, these 10 schools were selected: Bedfont Junior; Springwell Junior; Chatsworth Junior; Hounslow Heath Junior; Wellington Primary; Andrew Ewing Junior; Cranford Junior; Orchard Junior; Beavers Community Primary; Grove Road Primary. Andrew Ewing Junior was invited to take part in the study, but declined to participate on the ground that the year 4 teacher was new and there was already considerable research going on in the school being conducted by the DfEE. In Slough, 1 school was selected: Pippins School.

Four high noise schools were not approached at this stage and were not included for the following reasons:

- The Smallberry Green Primary and Worple Primary in Hounslow because they were SES outliers.
- Marlborough Junior in Hounslow because it was a new school built in the 1990s and had very different resources to the other high noise schools.
- Wraysbury Primary in Windsor & Maidenhead was not considered for inclusion at this stage because as it was extremely well insulated and was considered as back-up school.

2.3.2 The Matching Procedure - How schools exposed to high noise were matched with the control schools

First, we obtained a list of all eligible control primary schools in the Boroughs of Hounslow, Hillingdon, Slough and Windsor and Maidenhead around Heathrow Airport exposed to less than 57 dBA Leq aircraft noise according to the 1994 16 hour Civil Aviation Authority Contours.

Outright exclusion criteria

Secondly, potential control schools were excluded in the first instance if they:

a) had no pupils in the age range 8-11 years;
b) were single sex schools;
c) were schools for children with special needs;
d) were non-government schools;
e) were exposed to high levels of noise from non-aircraft environmental noise sources (road, rail and industrial noise). A school was excluded if there was a major source of environmental noise, such as, road traffic, rail or industrial noise. This was determined by measuring distances to the schools from A-roads, B-roads

and motorways by using maps and Geographic Information Systems software maps and site inspections of road traffic flow and actual exposure;

f) were close to the 57 dBA noise contour; this was determined by whether these schools had previously been classified as within the 57 noise contour (CAA contours 1991, 1994);

g) were exposed to aircraft noise from other airports, specifically Northolt Airport.

Site inspections were made of 23 low noise schools by research staff (MH & MJ) and local authority officers in June and July 1999 to determine the suitability of the control schools that were in the matching cells.

Matching Procedure

Thirdly, we matched low noise schools with high noise schools for socio-economic status and main language spoken at home at the school level.

Socio-economic status is the most important contributor to school performance and was given priority in matching. Socio-economic status was measured by the percentage of children eligible for free school meals in the school. This was obtained from the local education authorities from the 1997 school census. We decided to use free school meals rather than school ward level as 1991 census variables are now out of date. For a child to be eligible for a free school meal, the main wage earner in their household has to be receiving income support. There is a significant correlation between the free school meal ratio and a range of census indicators representative of socio-economic status. This suggests that, at least at the school level, free school meal ratios can act as a proxy for social disadvantage (Williamson & Byrne, 1977).

From our previous classroom studies around Heathrow Airport, we found that main language spoken at home influenced reading comprehension more than ethnicity. To take account of this, data on the proportion of children in the school whose main language spoken at home is not English was obtained from the 1997 school census (DfEE).

The matching procedure was as follows:

1) We stratified both the high and low noise schools separately by the proportion of free school meals (10 groups) and the proportion of children with Non-English as the main language spoken at home (3 groups). These groups were classified for percentage eligible for free school meal ranging from lowest to highest: 0-5; 5-10; 10-15; 15-20; 20-25; 25-30; 30-35; 35-40; 40-45; >45. These groups were classified for percentage of children with English as the second language from lowest to highest: 0-10; 11-30; 31-100. This produced two tables with 30 cells for the high and low noise schools (see Table 2 below for an example).

2) For each cell that contained a high noise school, a low noise school was randomly selected from the equivalent cell after exclusions. The advantage of this procedure over the closest paired match between high and low noise schools is that it was pre-specified and involved some random selection that may balance for other unmeasured confounding factors.

Matching criteria in order of priority:

1) Eligibility for free school meals;

2) Borough: If a Hounslow or Slough school, prioritise matching to a Hounslow, Hillingdon or Slough school, not a Windsor and Maidenhead school. If there is a Windsor and Maidenhead high noise school, match it to a Windsor and Maidenhead control school;

3) Main language spoken at home.

Table 2: Example Matching Table for Matching High and Low Noise Exposed Schools by SES and Language

% Eligible for a free school meal	**English Additional Language 0-10%**	**English Additional Language 11-30%**	**English Additional Language 31-10%**
0-5 %	Cell A	Cell B	Cell C
5-10 %	Cell D	Cell E	Cell F
10 – 15%	Cell G	Cell H	Cell I
15-20 %	Cell J	Cell K	Cell L
20-25%	Cell M	Cell N	Cell O
25-30%	Cell P	Cell Q	Cell R
30-35%	Cell S	Cell T	Cell Q
35-40%	Cell V	Cell W	Cell X
40- 45%	Cell Y	Cell Z	Cell AA
>45%	Cell BB	Cell CC	Cell DD

2.3.3 The Schools Selected and Response Rate

20 schools out of the 21 schools invited to take part in the study consented to take part. NB: see note above about Andrew Ewing Junior School in Hounslow. The schools selected are in Table 3.

Table 3: High and low noise schools in the West London Schools Study in their Social Class Matching cells, with borough and noise exposure noted

High Noise SES cells **N=10** **<63 dBA Leq**	**Low noise Schools in SES cells** **N=10** **>57 dbA Leq**
J Pippins School (Slough > 66 dBALeq)	**J - (best match)** Feltham Hill (Hounslow)
N Bedfont (Hounslow > 66 dBA Leq)	**N (best match selected)** Strand-on-the Green (Hounslow)
O Springwell (Hounslow > 66 dBA Leq) Chatsworth (Hounslow > 66 dBA Leq) Hounslow Heath (Hounslow > 66 dBA Leq)	**O (best 3 matches selected)** Grange Park Junior (Hillingdon) **M** Hillside Junior (Hillingdon) **P** Rabbsfarm Junior & Infant (Hillingdon)
R Wellington (Hounslow > 63 dBA Leq)	**R (best match selected)** James Elliman Junior (Slough)
U Cranford (Hounslow > 63 dBA Leq) Orchard (Hounslow > 63 dBA Leq) Beavers Community School (Hounslow > 66 dBA Leq)	**U (3 best matches selected)** Godolphin (Slough) Norwood Green Junior (Hounslow) **T** Brookside (Hillingdon)
X Grove Road Primary (Hounslow > 66 dBA Leq)	**X (randomly select school)** Lea Junior (Slough)

2.4 Materials

2.4.1 The Child Questionnaire and Tests

The content and wording of all the questionnaires and tasks were designed for an 8–9 year old sample. The child questionnaire was group administered to the child participants (see Appendix 2). There were two versions of the Suffolk Reading Scale. See Table 4 below for an outline of the parts of the child questionnaire. These measures will be described in detail below.

Table 4: An outline of the parts of the child questionnaire

Sections	Version and Parts
Consent Form and Information Sheet	
Socio-Demographic	1) Name 2) Sex 3) Date of Birth
Immediate Recall	Child Memory Scale Story C & D Immediate Recall
Reading Comprehension	Suffolk Reading Comprehension Test Level 2 Version 1: Form B Version 2: Form A
Delayed Recall	Child Memory Scale Story C & D
Delayed Recognition	Child Memory Scale Story C & D
Working Memory Central Executive Function	Backward Digit Recall 10 trials of 2 sets of 2,3,4,5,6 digits
Sustained Attention	Test of Everyday Attention for Children (TEACh) – Score Activity
Environment and Health Questionnaire	1) Self reported perceived home and school noise exposure from 4 sources of environmental noise: trains, road traffic, planes, neighbour noise 2) Aircraft and Road Traffic Noise Annoyance at school and at home 3) General Health and Symptoms (headaches, tiredness, trouble sleeping) 4) Lewis Child Stress Scale

Cognitive Measures

Reading Comprehension

A nationally standardised reading comprehension test was used to replicate the result from the Schools Environment and Health Study (Haines et al., in press a, in press b) and to replicate the German standardised reading comprehension measure used in Munich (Evans *et al*., 1995). Reading comprehension was measured by the Suffolk Reading Scale (Hagley, 1987) Level 2 with two versions (Form A & B). The Suffolk Reading Scale was designed to measure the reading ability and reading standards of 6 year 4 month to 13 year 11 month students in the United Kingdom. The Level Two Suffolk Reading Scale contains 70 multi-choice questions with 5 potential answers. The task was introduced as 'a complete the sentence activity'. The task was conducted in silence and timed out after 20 minutes. Each child was instructed to:

"Please choose which word fits best into the sentence. Look at each of the five words underneath the sentence. Sometimes more than one word will fit into the sentence. Decide which one fits best. Circle the word that fits in best. You may find some items more difficult than others. If you are not sure, circle the one that you think fits best. Only miss out a sentence if you really cannot do it."

For example:

1. You drink from a ________________ .

bean bus cup hop tack

The Suffolk Reading Scale was chosen over other reading comprehension scales because: a) it was normed for use on a racially and socio-economically mixed sample (Hagley, 1987); b) it has 2 forms which are required for follow up research; and c) it produces a standardised score. The Suffolk Reading Scale was standardised on a large, randomly selected and representative national sample of 38,625 primary aged school children. The scale has good construct validity being highly correlated with teacher's estimates of reading ability (Hagley, 1987). The test-retest reliability of scores, correlation between the parallel forms and internal consistency were high (Hagley, 1987). Age standardised scores range from -70 up to +130. The higher the score, the greater the reading comprehension.

Long Term Memory: Recognition and Recall

Long term memory was measured by a task similar to the long term memory task used in the Munich study (Evans *et al.,* 1995). The task used was adapted for group administration from the Child Memory Scale (Cohen, 1997) which is a normed and psychometrically valid long term memory task that is widely used in the USA and less widely used in the UK. The task was designed to measure the immediate and delayed recall and recognition of two stories after a 30 minute delay with an interference task. Specifically, this test assesses the ability to process, encode and recall meaningful and semantically related verbal material that is presented in a sequential format.

In the immediate portion, two stories are played on an audio-cassette. The reading passages (Stories C & D) were taken from the Child Memory Scale (Cohen, 1997), these stories are one paragraph long each (Appendix 3). A recording of these stories was played to the class of children, who were instructed:

“On a tape, there are 2 short stories that will be played. Listen carefully because, when the first story is finished, I'm going to ask you to write down as much as much of the story as you can remember. After the first story is finished, the second story will start.”

After each presentation the subjects were asked to write down as much as they could remember on a sheet. The recall portion is not timed out. This procedure occurs for story C, then the process is repeated for story D. After this immediate recall has been completed, the subjects were told:

“please remember both of these stories because you will be asked to remember them again later”.

In the delayed portion, after a 30 minute delay and interference task (Suffolk Reading Scale), the subjects were asked to write down as much as they could remember for story C and then story D. This delayed recall is not timed out. Recognition is assessed by reading out to the subjects 15 factual questions about each of the stories, which they have to answer by ticking yes or no on a sheet. The answers were scored by using a standardised procedure for the Children's Memory Scale (Appendix 4). 3 scores were calculated: 1) immediate recall (subscores for correct detail and themes); 2) delayed recall (subscores for correct detail and themes); and 3) recognition scores (number of correct answers).

Sustained Attention

Sustained attention or vigilance was measured with a sub-test taken from the Tests of Everyday Attention for Children (TEACh) battery of measures for the assessment of attention in children (Manly *et al.*, 1998, version A). This standardised and normed clinical assessment battery of measures of different attentional functions is designed for children from the ages of 6 to 16. The SCORE sub-test was group administered in the classrooms with a tape cassette. If any source of noise or classroom disturbance interfered with sound perception on any trials, then the trial was re-played. TEACh is designed for individual assessment and testing should take place on a one-to-one basis, so the results may not entirely match up with the normative data. Advice was taken from a member of the team who developed the test who felt that group administration of SCORE would still provide valid results (personal communication Tom Manly) and this was supported from the results from the Schools Environment and Health Study (Haines et al., 1998).

SCORE is a version of one of the best validated measures of sustained attention in adults (Manly *et al.*, 1998). In SCORE, children are asked to imagine that they are keeping score by counting the scoring sounds in a computer game. This test measures ability to count tones with irregular inter-stimulus intervals. The children were instructed with: "This test is all about counting. I am going to play you this tape and you have to count how many sounds you hear - as if you were keeping score by counting the number of scoring sounds in a computer game.... For each game count the number of sounds and write down how many you heard." The children were not allowed to count on their fingers. There are 10 trials, each scored for correct number of items counted. The raw scores range from 0 - 10. The higher the score, the better the sustained attention.

An auditory sustained attention task was chosen over a visual task because it is less likely to be confounded by visual and reading abilities. This sample of children was known not to have any hearing difficulties, which could potentially affect an auditory task. These tests are designed to be appealing to younger children without patronising older children. The tone of the tests is of a game, particularly the style and imagery associated with computer games, that gives the assessment greater ecological validity. Ecological validity refers to the capacity of a measure to tap skills which are required in day-to-day life rather than skills that are required to perform successfully in a laboratory. Because these tests are presented in a computer game-like context they are more ecologically valid.

Normative data from 293 children is currently being collected and analysed, however some preliminary results are known (Manly *et al.,* 1998). The test-retest correlation coefficients after 6-15 days re-administration were high for the SCORE Test. The pattern of results comparing this measure of sustained attention with other cognitive measures provide further indication of the validity of TEACh, especially the SCORE task. As expected, SCORE did not correlate with measures of selective attention nor IQ of general ability (WISC-R), but it did correlate significantly with measures of response impulsivity, reading, spelling and arithmetic achievement scores. These correlations indicate that SCORE is a highly sensitive measure of sustained attention in healthy children.

Working Memory-Central Executive Function

A backward digit recall task is designed to measure central executive function, one component of working memory as outlined in the working memory model originally proposed by Baddeley & Hitch (1974). This function is measured by a backward digit recall task, because it measures the ability to hold onto the list of numbers that are presented in forwards order and to reverse them for recall, thus being a measure of simultaneous processing and maintenance. Random digit sequences of graduated length were presented to the class on an audio-cassette (Appendix 5). The subjects were asked to write the digits down in the reverse order of that presented orally. The subjects were timed out for 20 seconds per trial. This test, which has been widely used in children's testing batteries (WISC-III; CMS; The working memory battery Pickering and Gathercole, 2000), is normally individually administered with a discontinuation rule: that the test is stopped when the child is unable to respond correctly on two trials of a particular sequence length. In adapting this test to group administration we had to administer enough trials so that we could obtain a valid range of scores, without presenting too many trials so that the children would feel frustrated and unmotivated. The mean digit span for 8 to 9 year old children is 3 to 4 digits (WISC-III; CMS). Thus we decided to administer 10 trials with 2 sets of each of these digit sequences: 2,3,4,5,6.

Three scores were calculated: 1) correct number of trials with all numbers in correct backward serial order; 2) digit span 1 - the number of digits in the penultimate trial before the failure – this is the conventional span score most widely used; and 3) digit span 2 - the number of digits where the child correctly answered both trials of the same length.

These are the standardised interpretations of digits spans in WISC-III: 2 digits =borderline impaired; 2-3=low average; 3-4= average; 5=high average; 6+ = superior.

The Stress Response and Health Measures

Noise Annoyance

Noise annoyance was measured with 4 child adapted standard questions (Fields *et al.,* 1998). These questions assessed the level of annoyance, on the 5 point likert scale (extremely, very much, quite a bit, a little, not at all) and the 10 point scale, felt by the child when they heard aircraft noise and road traffic noise at home and school in the last 12 months. These questions produce two scores, on which the higher the score the higher the noise annoyance (range 0 – 4 for likert scale and the ten point scale 0-10).

Self-reported Stress – Lewis Child Stress Scale

Child stress was measured with the child stress scale (Lewis et *al.*, 1984). The scale consists of 20 stress-provoking circumstances that were generated through interviews with children concerning sources of stress in their lives. The child stress scale was selected because it operationally defines ‘stress’ from the child’s perspective and has been used in previous research with children (Lewis et al., 1984; Lewis & Lewis, 1985; Brown & Siegel, 1988). The 20 items included situations that would make children feel bad (e.g. not having homework done on time), nervous (e.g. changing schools) or worried (e.g. not getting along with your teacher). The 20 items were repeated in two subscales. The first scale asks the children to rate how bad would they feel if each of the 20 situations happened to them on a 5 point scale: ‘not bad’, ‘a little bad’, ‘pretty bad’, ‘very bad’, ‘terrible’. The second scale asks the children to rate how often each of the 20 situations happened to them on a 5 point scale: ‘never’, ‘once or twice’, ‘sometimes’, ‘often’, ‘all the time’. Two scores were used in the analysis: 1) a perceived stress score: a summation of the first scale how bad would they feel if an event happened to them; and 2) a frequency score**:** a summation of the second scale to calculate how often negative life events had occurred

Normative data from 2,480 5th grade American students found high internal consistency (alpha=0.82) with the feel-bad score (Lewis et al., 1984). A principle components factor analysis on the same data set with varimax rotation yielded three factors of the scale: 1) anxieties surrounding conflicts with parents; 2) self-image, self-esteem and peer-group relationships; and 3) dislocations (changes in living arrangements) (Lewis et al., 1984).

Catecholamines: Noradrenaline and Adrenaline

A subsample of the study population were tested for overnight urinary catecholamines (adrenaline, noradrenaline) and cortisol. Creatinine was measured as an adjustment variable. 16 schools (8 high noise and 8 low noise) took part. Information and instruction sheets were distributed to parents and children in order to explain the collection procedure (appendix 6). Each child was given a polythene, leak proof, 500ml, wide mouth container, containing 5g of ascorbic acid which acted as a preservative, as a collection vessel. The collection was a 12 hour overnight sample commencing at 8.00pm and terminating at 8.00am. The collection began the evening of the visit and the children were instructed to bring the sample back to school the following morning. The samples were collected and decanted. The assay of catecholamines, creatinine and cortisol was undertaken by the Clinical Biochemistry Department at Hope Hospital in Salford, Manchester. Adrenaline and noradrenaline were assayed using high-performance liquid chromatography (HPLC) with electrochemical detection (Rosano et al., 1991) and cortisol was measured using radioimmunoassay (RIA) (Moore et al 1985).

2.4.2 Parent Questionnaire

A questionnaire was sent home with the child for a parent or carer to complete, with the mother or female carer suggested as the preferred respondent. This questionnaire measured: child physical and mental health; parents general health; parent's perceived noise annoyance; and socio-demographic variables. An outline of the parts of this questionnaire are in Table 5 below and the questionnaire is in Appendix 7. Further detail about the source of measures will be outlined below this table.

Table 5: An outline of the questions in the parent questionnaire

Sections	Question
Child Health	* General child health * Sleeping difficulty * Hearing * Respiratory Health * Long standing illness * Psychological health (Strengths and Difficulties Questionnaire)
Parental Health	* General Health * Cohen Perceived Stress Scale
Environment	* Perceived noise * Noise annoyance
Socio-demographic and Deprivation indices	* Age * Ethnic Group * Language Spoken at home * Marital status * Mother's Education Level * Current employment status * Occupation and employment status of the highest income householder * Total household income * Benefits * Length of time living at the current address * Home ownership * Access to car * Central heating * Quality of housing * Extent of household sound insulation * Crowding * Number of children in the household

Child General Health and Symptoms

These questions were taken from questionnaires that are widely used in the UK in household surveys and questionnaires specifically designed to measure parental reporting on child health. The questions about child general health and longstanding illness were taken from the Health Survey for England (Prescott-Clarke & Primatesta, 1998). The questions about hearing loss were adapted from the Medical Research Council National Study of Ear, Nose and Throat Problems, with the two most sensitive items being an open question about difficulty with hearing, with prompts for glue ear and tinnitus and a question about hearing in background noise. Five questions were included from the ISSAC questionnaire (Asher et al, 1995, Kaur et al, 1998) of child respiratory health. Sleeping difficulty was measured with a question taken from the Rutter A2 parent questionnaire (Rutter *et al.*, 1970), including screening for: getting off to sleep; waking during the night; early morning waking; and bed wetting on a regular basis. Child psychological health was measured with the Strengths and Difficulties Questionnaire (SDQ: Goodman, 1997). This questionnaire asks about 25 attributes, 10 of which are considered strengths (e.g. 'thinks things out before acting'), 14 of which are considered difficulties (e.g. 'often unhappy, down-hearted or tearful') and one of which is neutral ('gets on better with adults than with other children'). Each item is marked as 'not true', 'somewhat true' or 'certainly true'. The advantage of the SDQ over other scales is that it focuses parents on children's strengths as well as weaknesses, which: a) increases parent compliance; and b) reduces the possibility of halo effects. The SDQ contains 5 sub-scales: hyperactivity scale; emotional symptoms scale; conduct problems scale; peer problems scale; and prosocial scale. A total difficulties score can be calculated by the summation of the hyperactivity, emotional, conduct and peer problems subscales. The higher the score, the greater the total difficulties.

Parental Health

The general self-reported health question was taken from the standard question used in health surveys. Perceived stress was measured with the Cohen Perceived Stress Scale (Cohen *et al.,* 1983). This stress scale aims to measure the degree to which situations over the past month are appraised as stressful and included questions about the unexpectedness, controllability and amount of stressors. The 10 items refer to subjective appraisals of events occurring within a one-month time frame. Higher scores indicate more perceived stress.

Perceived Noise Exposure

Self–reported noise exposure at home over the last 12 months was measured from 4 sources of environmental noise (road traffic, neighbours, aircraft and train).

Noise Annoyance

Noise annoyance was measured with 4 standard questions (Fields *et al.*, 1998). These questions assessed the level of annoyance, on a 5 point likert scale (extremely, very much, moderately, slightly, not at all) and the 10 point scale, felt by the parent when they heard road traffic, neighbour, aircraft and train noise at home, in the last 12 months. These questions produce two scores on which the higher the score the higher the noise annoyance (range 0 – 4 for likert scale and the ten point scale 0-10).

Socio-Demographic Questions

These questions were taken from the most current questionnaires that are widely used in the UK in household surveys and questionnaires specifically designed to measure indices of social position and deprivation. Ethnic Group was measured using a question from the 2001 Census. Language Spoken at home was measured with a question used in the 4th National Survey of Ethnic Minorities (Nazroo, 1997). Mother's education level was measured with a question adapted from the Health Survey for England (Prescott-Clarke & Primatesta, 1998) and Gender Inequalities in Nursing Careers (Finlayson & Nazroo, 1998) and included a question on qualifications obtained from non-British institutions. The following items were measured with questions taken from the Health Survey for England: occupation and employment status of the highest income householder; total household income; benefits; home ownership; access to car; central heating; quality of housing; and crowding (Prescott-Clarke & Primatesta, 1998).

2.4.3 Teacher Questionnaire and Access to School Records

A questionnaire was administered to the class teacher of each class taking part in the West London Schools Study. It was divided into two sections (see Appendix 8 for the questionnaire). Section 1 contained questions about the teacher's self-reported general health and their perceived stress (Cohen Perceived Stress Scale). Section 2 contained the standard questions to assess perceived noise exposure at school from road traffic, aircraft and trains. It also contained the standard noise annoyance questions for road traffic and aircraft noise at school (Fields *et al.,* 1998).

For each child taking part in the study these data were collected from the school: Key stage 1 results; length of time attending the school; date of birth; home address; recent stressful life event; statemented as having a special need; hearing problems; ethnicity; and languages spoken at home.

2.5 Procedure

2.5.1 Ethical Approval and Procedural Techniques

Ethical approval was granted by the following three ethics committees to conduct the study.

1) East Berkshire Research Ethics Committee
2) The Hillingdon Health Agency Ethics Committee
3) The Ealing, Hammersmith and Hounslow Health Authority Hounslow Research Ethics Committee

Ethical measures that were used in the study were: child and parent written consent for participation; and child and parent information sheets. Children were free to withdraw from the study at any point and did not have to answer any question they did not want to. One child from a low noise school and 3 children from a high noise school refused to take part in the study. Children were debriefed after each testing session.

Pilot Study

A pilot study was conducted in October 1999 to test the procedure and materials on a year 4 sample and their parents at Charville Junior School in Hillingdon. Practical aspects of noise measurement in the classroom environment, such as the potential disruption by the equipment, cables and staff, were also piloted. On the basis of this study, refinements were made to the protocol of the classroom testing, and questionnaires, and steps were taken to improve response rate. The main findings of this pilot study were that children complied with the tests and the instructions were clear. The 18 parents who completed the parent questionnaire fully answered the detailed socio-demographic questions and found them easy to understand. The response rate of the pilot study was 70% which is adequate, but it was felt that further action needed to be taken to improve this response rate to 80-90 %. This included making direct contact with the class teacher prior to testing and close monitoring of the response rate of parental consent prior to school arrival. Verbal instructions and verbal stimuli for the cognitive tests were pre-recorded for presentation through high-quality audio equipment (supplied by National Physical Laboratory).

2.5.2 Protocol for Classroom Testing at the Schools

The local education authorities and head teachers were approached and asked for permission to conduct the study in their schools. Parents of the sample were sent letters explaining the research, an information sheet and a consent form to be signed (see Appendix 9). The study was introduced as a Health and Environment study to the teachers, parents and children. This introduction did not focus on noise to avoid response bias, a technique successfully used in previous studies (Job et al, 1991b). After this initial letter of invitation was distributed, it became apparent that response rates varied between schools. A response rate strategy was employed to target schools identified with a low response rate. These schools had subsequent letters distributed to the children, a member of the research team visited the schools and, finally, telephone contact was made with parents by either the school or the research team. This strategy was employed to ensure that the final sample was representative of the sample invited to take part in the study.

In October and November 1999 testing was conducted in the twenty schools. The testing day for each school was randomly selected in an alternating high noise school followed by a low noise school pattern. Testing was conducted at schools on 4 days of the week. It was necessary to counteract any effect of a ‘day bias’ on testing. To avoid a day bias, such as always visiting a high noise school on a Monday or a low noise school on a Friday, each week commenced with the alternating high and low noise schools.

Cognitive performance tests and the questionnaires were group administered to the children in the morning in the classroom (for verbal instructions see Appendix 10). Although the tasks were administered in the classroom, the tasks were carried out individually under exam conditions (see Appendix 11 for monitor protocol). Child health and environmental attitudes were measured by a multi-choice questionnaire that was read aloud to the children to reduce the possibility of reading ability influencing the results. Group administration was used since a questionnaire completed in a group situation is known to be conducive to co-operation in answering sensitive questions (Job & Bullen, 1987). Testing was conducted in the classrooms in which the children learn in order produce a more realistic setting. Children's performance may be a more accurate assessment of their everyday functioning than laboratory testing as the testing was conducted in the same situation that all other school performance is measured.

The testing was conducted controlling for time of day across noise exposure (see Table 6, below). The question order varied in some schools due to the pragmatic constraints of break times for the children. The immediate and delayed recall task was conducted in the same session so that the children would not talk to each other about the stories at break time. The Lewis Child Stress Scale was given as the last task of testing so that any transient mood effects possibly induced from completing the psychological scales would not affect any other task.

Children who were identified as having a severe learning problem were assisted by the researchers. These children were already excluded on 'a priori' grounds (see exclusions section). This small sub-group were assisted so that they were not upset by failure and so they felt they could take part in the project. These children were identified by the class teacher prior to testing and were made known to the research team. This was the protocol used by the researchers to assist these children: 1) performance monitored by research team; 2) at the first sign of distress encouragement was given; 3) if there was further distress, help was given and noted in the research log book; 4) child given alternative task if they wanted it.

Table 6: An outline of the protocol of the classroom testing at follow-up

	Session 1	**Session 2**
Research Activities	Explanation of the study to the children	Backward Digit Recall
	Information sheets Handed out the children	Sustained Attention
	Child and parental written consent obtained.	Health and environment questionnaire
	Immediate Recall	Explanation of the Catecholamines
	Reading Comprehension	Debriefing
	Delayed Recall	
	Delayed Recognition	Noise measurements Throughout
	Acute noise measurements throughout	
Time Taken	90 minutes	60 minutes

2.5.3 Procedures Adopted to Attain Reliable Results with a Child Sample

Many procedures were adopted to increase the likelihood of obtaining reliable results. Question order effects were accounted for by controlling, as far as practically possible, the question order across the schools. Noise questions were embedded in the health and environment section to counter the possibility of 'halo effects' biasing responding. Socio-demographic data were collected from the school records on the whole sample approached in order to check for representativeness of the participating sample. The distribution of ethnic group and main language spoken at home was compared between the eligible sample and those who agreed to take part in the study. There was no difference in socio-demographic variables between the participants and those who declined to take part.

To ensure reliable child data the following techniques were used:

1) The introduction and child consent form implied an informal contractual commitment for the co-operation and honesty of the children. It has been shown by Oksenberg, Vinokur & Cannell (1979) that an implied contractual agreement promotes a degree of accuracy and completeness of answers.

2) The scientific importance of the research was signaled which is a technique used to promote serious responding in child samples (Fisher & Leitenberg, 1986; Haines & Job, 1994).

3) At least three members of the research team were present at testing (SB, MJ, RR), who vigilantly monitored in a systematic fashion that all children were complying with the instructions and not cheating (see appendix 11 for monitoring protocol).

4) Psychological scales and questionnaires were read aloud by the researcher to avoid differences in reading ability affecting self-report. This technique is known to increase the validity of the responses.

5) The children were encouraged to ask questions for clarification of the instructions.

6) To guard against the likelihood of the children producing 'expected answers' the fact that there was no right or wrong answer was stressed verbally.

7) Each part of the questionnaire was collected by the researchers immediately after completion. This procedure was adopted to: a) ensure that the subjects answered the questions in the correct order; and b) that they could not look over previous answers.

8) The researchers adopted a 'task-oriented' approach that has been found to produce more accurate data (Cannell, 1979).

2.5.4 Noise Measurement Procedure

Noise measurement procedure was the same at the high noise and the control schools

Chronic Noise Measurements

The key exposure examined in this study was aircraft noise (air noise, rather than ground noise) from the aircraft taking off from and landing at Heathrow Airport.

Schools were chosen within the published 1997 Civil Aviation Authority dBA Leq, 16hr (92 days) contour maps indicating the average continuous equivalent sound level of aircraft noise within a particular area for 16 hour daily periods during June 15 to September 15. The high aircraft noise exposure schools were exposed to aircraft noise levels greater than 63 dBA Leq (taken from the 1997 CAA contour maps). The high aircraft noise exposure contour includes the residential areas with the highest exposures round Heathrow airport. Low aircraft noise exposure schools were located outside the 57 dBA Leq contour. (For the dBA Leq, and maximum sound levels for each school see Results section).

Acute Noise Measurements

Throughout the cognitive testing, internal and external noise levels were monitored continuously. A microphone was placed inside the classroom and another microphone was placed outside the school building; both were connected to a PC. Noise monitoring was performed using a laptop PC based system, Symphonie from the manufacturer 01dB. Data was acquired as ‘A’ weighted and one-third octaves spectral parameters from both indoor and outdoor microphones simultaneously at 100 millisecond intervals.

During data acquisition, signals from either microphone could be monitored using headphones. Notes were made of the layout of the school, the prevailing weather conditions and the flight path of any aircraft flying nearby for each school visited. Digital photographs were also used extensively to record details of the internal and external microphone locations.

Noise data gathered from this exercise provided:-

- Average, minimum and maximum external aircraft SEL’s.
- Average, minimum and maximum external SEL’s of other sources.
- Hourly values of L_{Amax}, L_{Aeq}, L_{A10}, L_{A90} inside and outside the school.
- An indication of the outdoor to indoor level difference for aircraft noise events.
- Total individual external source levels, cumulative duration and number of events.

- Details of the significant sources of external environmental noise.
- A brief description of the type of building and location.

Dosimetry

A trial of personal dosimetry was carried out in 8 schools (4 high and 4 low) in order to assess usefulness and practicality of the technique. The instruments used were CEL 460 logging dosimeters set up to acquire one second values of L_{Aeq} & L_{AMax} for the whole duration of testing. A male and female student from another year 4 class were selected. The dosimeters were worn by the children in their own classrooms during normal classroom activities, simultaneously through out the whole morning as the cognitive tests were administered. The Dosimeter was clipped to the child's waistband and the microphone attached to their clothing at shoulder level. Each child was instructed not to let classmates shout into the microphone, not to interfere with it and were reassured that the dosimeter only measured noise levels and did not record conversation. The manufacturer supplied small windshields that were taped on to the microphones to afford some protection against knocks.

Actual aircraft movement data

Data on actual aircraft movement at each participating school were also taken from the 1999-2000 Civil Aviation Authority movement data and, where possible, based on average measured single event levels. It was calculated from this data how much of the aircraft movements on easterly and westerly operations, on each runway and each flight path would affect each school in terms of noise exposure. For each of the twenty schools, a predicted 8 hour, school day LAeq was calculated. From this the total LAeq, 8hr for each school for 96 days was calculated. The dates included were only during term time and all preceded testing.

Other Noise Exposure

Data on aircraft noise exposure levels at each participating child's home were also taken from the 1997 Civil Aviation Authority dBA Leq-16hr (92 days), using GIS contour maps for the area surrounding Heathrow Airport as was self reported home and school noise exposure from 4 sources of environmental noise (trains, road traffic, planes, neighbour noise). The noise measurements taken at the time of testing also quantified the exposure to these other sources of environmental noise (road and trains). Length of time that the child had been enrolled in the school was collected from the children and school records.

2.5.5 Statistical Procedures

All statistical tests are two-tailed and alpha was set at 0.05.

Multivariate between subjects analyses of main effects

Analyses of Covariance (ANCOVA) were used to examine the cross-sectional main noise effects and general linear model (GLM) repeated measures for item analysis with two models in SPSS for windows version 10.0. General Linear Two models were used: model 1 was age adjusted and in model 2 three factors were adjusted for namely: age (at the time of testing); main language spoken at home (a variable with two levels: English and non-English); and deprivation (a continuous variable). Analyses additionally adjusted for maternal educational attainment are in the footnotes. These factors were included in the analyses to control for the possibility that any difference in cognitive performance between high and low noise groups might be explained by socio-demographic factors. The possibility of type II errors being increased by the number of main analyses conducted will be considered in the interpretation of the results.

Deprivation

The household deprivation score was calculated on a scale adapted from Townsend's Scale (Townsend *et al.,* 1989) by incorporating: income; home tenure; car ownership; employment status; central heating; social class; and household crowding in a single scale. The number of indicators of household deprivation reported out of these 7 indices were summed and a total deprivation score calculated (Townsend *et al.,* 1989). Household deprivation was chosen as a confounding factor to use for adjustment rather then social class, because the latter is not considered to be a satisfactory indicator of social disadvantage (Bartley, *et al.,* 1994) These data were collected from the parents. Deprivation was entered into the analysis as a continuous covariate.

Main Language Spoken at Home

It is reasonable to assume that main language spoken at home could influence English performance, therefore, main language spoken at home was entered as a covariate in the ANCOVA models. Main language was selected over ethnicity because if adjustment is made for ethnicity it is unclear exactly what this controls for (e.g. cultural differences, motivation, language proficiency and fluency etc.) and main language spoken at home has obvious relevance to school performance. Main language has two levels: English and non-English.

Multi-level modelling

The analysis used multilevel modelling (Goldstein, 1995) for the following reasons. The data collected is hierarchical with pupils clustered within schools. Using multilevel terminology, there are two levels of units. The level 1 units are pupils who are clustered within the level 2 school units. Multilevel modelling makes best (or statistically efficient) use of these data rather than having to choose whether to analyse at the individual or school level, neither of which is satisfactory (Thompson et al., 1997). The multilevel method produces correct standard errors and significance tests as the analysis takes account of the clustered nature of the data. Another advantage is that both variables at the school level and the pupil level (e.g., age, main language spoken and household deprivation) can be included in the same model. Finally, one can see whether noise effects 'explain' any of the variation in cognitive performance and annoyance scores between schools.

The multilevel models were fitted to the data using the statistical package, MLn, which was written by statisticians from the Institute of Education, University of London. Models including the possible explanatory variables were fitted. The output from these analyses will be reported as the fixed coefficients and standard error for noise level for each of the explanatory variables in the model: this can be interpreted just as in ordinary multiple regression. Statistical significance is tested by comparing the goodness of fit of two alternative models and testing whether the improvement in fit is statistically significant. This method has been used to produce the significance levels given in the text for the statistically significant associations. As with the multivariate analyses, two models were used: model 1 was age adjusted and in model 2 three factors were adjusted for namely: age (at the time of testing); main language spoken at home (a variable with two levels: English and non-English); and deprivation (a continuous variable). Results for the multi-level models indicated that there was little school level variation in the health measures. In this situation, estimates and standard errors from the multi-level models are the same as for the analyses of covariance. Thus, the tables of results for health only include the analysis of covariance.

Exclusions

The ‘a priori’ criteria for excluding subjects were divided into 2 categories: 1) those participants that were excluded from all tests; and 2) those that were excluded from the cognitive tests. Information about language, hearing and difficulties data were collected from the teacher and parent questionnaires. The exclusion cases were decided upon by three researchers (one blind to the noise level of the school).

Exclusions from all the Tests

The 3 criteria were:

1) Children with very little English, who could not understand the tests, tasks and questionnaires.
2) Children who had a learning difficulty that was so severe that they were helped throughout the testing.
3) Children with severe hearing difficulty and fine motor skills problem.

Results from eight subjects were excluded from all tests (6 high noise, 2 low noise); 7 subjects were excluded because they had very little English and 1 because of a very severe learning difficulty. No child had a severe hearing or fine motor skills problem.

Exclusions from the Cognitive Tests

The 3 exclusion criteria were:

1) Children with a learning difficulty that were helped through out the cognitive tests to the extent that their answers were not their own and that they didn't comply with the instructions
2) Children that had a non-English language as their main language and had very poor English language skills, to such an extent that they couldn't understand the instructions
3) Children that were deemed to have cheated on a test. In practice this only applied to the backwards digit task. Children founded to have cheated twice or more on this task were excluded.

Results from 8 subjects were excluded from the cognitive tests (6 high noise, 2 low noise). 8 subjects were excluded from all tests; the results from 19 subjects were excluded from the Suffolk reading test because they were assisted; the results from 12 subjects were excluded from the backward digits because they cheated.

Threats to Validity and missing data

The following threats to validity were addressed prior to the data analysis: question and version effects; floor/ceiling effects; social desirability; and patterns of missing data. None of these potential problems substantially influenced validity of the data. Value substitutions were made for missing data on the psychological scales. Only a small number of subject's total scores were excluded because of missing data. Value substitutions were made for main language spoken at home reported by parents using school records. Value substitutions were made for deprivation with eligibility for free school meal collected from the school as a proxy measure of social deprivation.

Results Presentation

All statistical tests are two-tailed and alpha was set at 0.05. The results tables will contain mean scores adjusted for age, main language spoken and deprivation, a difference score, 95 % confidence intervals, standard errors, F-statistics and p-values for the 10 high noise schools and the 10 low noise schools. Difference score is the low noise mean minus the high noise mean. Confidence intervals are given for all difference scores. Noise co-efficients and standard errors for the age adjusted and fully adjusted multi-level models are also contained in the Tables for the most important results.

3. RESULTS

The results for The West London Schools Study will be outlined in this section which is ordered into 7 main sections: 3.1) descriptive results; 3.2) noise exposure; 3.3) the effects of noise on child cognitive performance: multivariate and multi-level analysis; 3.4) the effects of noise on child annoyance: multivariate and multi-level analysis, annoyance, health and cognitive effects on children: multivariate analyses; 3.5) noise effects in sub-groups of children: stratified analyses; 3.6) the effects of noise on child stress and health: multivariate and multi-level analysis; 3.7) health effects of noise on parents and teachers

3.1 Descriptive results

Response Rate

The overall response rate to the study was high (82%) (Table 7) with no evidence of differential response rates across noise exposure. Refusal to take part only accounted for just over 5% of the sample.

Table 7: Response Rate

Response Options	High Noise Eligible Sample N=284	Low Noise Eligible Sample N=265	Total
Participated	236 (83.1%)	215 (81.1%)	451 (82.1%)
Declined (parent)	9 (3.2%)	18 (6.8%)	27 (4.9%)
Declined (child)	3 (1.1%)	1 (0.4%)	4 (0.7%)
Holiday	1 (0.4%)	1 (0.4%)	2 (0.4%)
Sick	9 (3.2%)	13 (4.9%)	22 (4.0%)
Non-responders (no slip returned)	26(9.2%)	17 (6.4%)	43 (7.8%)

Samples

The samples were well matched by age and the proportion of boys and girls was very similar across high and low noise schools. Children from high noise schools were more likely to be non-White and to speak a language other than English as their first language at home (Table 8). Nevertheless, although it was difficult to match on ethnicity across high and low noise areas, as the noise exposed areas East of the airport contained predominantly ethnic minority populations, it was more possible to match for level of social disadvantage. Mother's educational status did not differ between high and low noise.

Schools were originally matched on the proportion of families in each school eligible for free school meals, an index of eligibility for social benefits. This careful matching is echoed in results across noise for three measures of social disadvantage obtained from the parent's questionnaire: employment status, crowding and deprivation. The proportion of households where the head of household was in full time employment, and household crowding and household deprivation did not differ across high and low exposure areas (Table 8). There were slightly more children from manual social class in the low noise schools (56.3%) compared with children in high noise schools (42.8%, p=0.03).

Table 8: The socio-demographic characteristics of the high and low noise child samples: frequencies and proportions, continuity correction chi-square p-value

Socio-Demographic Characteristic Total	**High Noise N=236**	**Low Noise N=215**	**Chi-square P-value**
Age	8 yrs 8 mnth	8 yrs 9 mnth	
Girls	50.4% (119)	47.9% (103)	
Boys	49.6% (117)	52.1%(112)	P=0.66
White	34.7% (82)	54.0% (116)	
Non-White	65.3% (154)	46.0% (99)*	P=0.01
English – Main Language Spoken at Home	58.5% (138)	70.1% (150)	
Non-English	41.5% (98)	29.9% (64)*	P=0.01
Mother's Education Status			
Degree or equivalent	9.1% (16)	9.0% (15)	
A level and other higher education below	21.7% (38)	13.9% (23)	
degree	38.3% (67)	44.6% (74)	
GSCE/O-level/equivalent	30.9% (54)	32.5% (54)	P=0.28**
No qualifications			
Not deprived	60.9% (143)	61.2% (131)	
Deprived	39.1% (92)	38.8% (83)	P=1.000
Crowding	18.4% (32)	18.9% (32)	
Not crowding	81.6% (142)	81.1% (137)	P=1.000
Non-manual social class	57.2% (79)	43.7% (62)	
Manual social class	42.8% (59)	56.3% (80)*	P=0.03
Head of household in full-time employment	75.7% (178)	79.0% (169)	
Head of household not in full-time employment	24.3% (57)	21.0% (45)	P=0.48

* P>0.05, **likelihood ratio

Note1: missing data for language (0.2%), mothers education status (24%), deprivation (0.4%), crowding (24%), social class (38%) and employment status (1.3%) Missing data for employment status and deprivation were imputed with %FSM. Missing data Race and Main Language were imputed with school record.

Note 2: Deprivation is a scale summation of these indices: income, home tenure, access to car ownership, employment status, central heating, social class, household crowing. Two indices or above indicated deprivation. Continuous variable was entered into ANCOVA models.

3.2 Noise Exposure

Perception of Noise

The majority of children in high noise schools heard aircraft noise at school (95%) and at home (94%) (Table 9). High noise school children heard significantly more aircraft noise than low noise school children. On the other hand, children from both high and low noise schools were exposed to fairly similar levels of exposure to other noises at school and at home, although, unexpectedly, children in low noise schools were exposed to significantly more road traffic noise than children in high noise schools.

Table 9: Perception of Noise: Proportion of children who could hear these noise sources at school and home

Perception of noise	**High Noise Schools**	**Low Noise Schools**	**Chi-Square p-value**
At School			
Aircraft	95% (221)	72% (152)	P=0.0001
Road	47% (108)	59% (126)	P=0.01
Rail	14% (33)	14% (30)	P=0.99
At Home			
Aircraft	94% (218)	69% (147)	P=0.0001
Road	67% (155)	73% (155)	P=0.18
Rail	15% (35)	21% (45)	P=0.11
Neighbours	58% (136)	65% (139)	P=0.14

Home Noise Exposure

74% of the high noise sample lived in high aircraft noise exposed homes (>63 dBA Leq 16hr). 96% of the low noise sample lived in low aircraft noise homes (<57 dBA Leq 16hr). This justified our choice of primary school children, who live fairly close to their schools as being suitable for the study of day-long noise exposure.

Outdoor Acute Noise Exposure

Table 10 contains the acute levels of aircraft noise at the time of testing in single event noise exposure levels (SEL dBA). There was a difference between high and low chronic aircraft noise exposed schools in terms of acute aircraft noise exposure during testing.

Table 10

Acute aircraft sound levels at the time of testing on Day 2 by class

Class	**Mean SEL DBA**	**Max SEL dBA**	**Min SEL dBA**	**Number of Aircraft Events**
High Noise Schools				
School BF	72.2	90.6	57.6	46
School BP	89.7	113.9	60.7	124
School CJ	86.8	110.7	79.3	105
School CW	72.5	84.5	67.1	79
School GR	74.6	87.0	65.4	85
School HH	88.2	94.5	83.3	121
School OJ	76.0	80.0	71.8	82
School PS	92.3	119.6	78.1	128
School SJ	71.1	75.6	64.0	72
School WP	85.9	99.0	80.6	41
Low Noise Schools				
School BJ	74.9	94.2	68.6	13
School FJ	78.2	96.0	72.1	21
School GJ	73.1	84.3	66.5	46
School GP	74.0	78.9	68.6	4
School HJ	-	-	-	0
School JE	76.7	84.6	70.0	4
School LJ	74.2	75.3	73.1	2
School NG	73.2	74.0	72.4	2
School RF	78.5	82.6	74.3	2

School SG	79.0	81.2	74.7	5

Indoor Noise exposure

Table 11 shows calculations using the level difference to relate outdoor noise contour values to indoor values, with windows closed and open, in the high noise schools. For those schools where measurement data was not available for the level difference with windows open, the cell in the table is shown dashed. In some schools (high and low noise) windows did not open. From the results in Table 11 it is clear that there is a wider range of internal noise exposure levels compared with using external contour values alone. This is due mainly to the large differences in the sound insulation performance of the different schools. Where windows are opened for ventilation internal exposure values are higher still, therefore, the total range of internal noise exposure across all high noise schools is even greater. Internal levels of exposure did vary within high aircraft noise exposed schools, and an analysis of the cognitive results has been conducted on the basis of this reclassification of noise exposure in Appendix 12.

Table 11 Table of measured outdoor and calculated indoor noise contour values for the high noise schools (rounded to whole decibels). The values in brackets are an average of the shown range. The schools are ranked by the average indoor calculated $L_{Aeq,16hr}$ with windows closed.

School Code	Outdoor $L_{Aeq,16hr}$	Indoor $L_{Aeq,16hr}$ (windows closed)	Indoor $L_{Aeq,16hr}$ (windows open)
BF	66 – 69	46 – 49 (47.5)	51 – 54 (52.5)
CW	66	46 (46.0)	(2) -
SJ	66 – 69	44 – 47 (45.5)	52 – 55 (53.5)
CJ	63 – 66	44 – 47 (45.5)	49 – 52 (50.5)
WP	63 – 66	36 – 39 (37.5)	53 – 56 (54.5)
PS	69	37 (37.0)	(1) 37 (37.0)
BP	66 – 69	35 – 38 (36.5)	(2) -
HH	66 – 69	32 – 35 (33.5)	(2) -
GR	66 – 69	31 – 34 (32.5)	(2) -
OJ	63 – 66	24 – 27 (25.5)	(2) -

(1 - Fire exit door open only. 2 – No data available)

Personal Dosimetry

Table 12 shows the results obtained from the dosimeters as hourly $L_{Aeq's}$ and a total $L_{Aeq,3hr}$ value for each subject. From these results it is clear the noisiest period was between 10am and 11am for each school, covering the time when the children were at morning break. The data indicates that although children were in both high and low noise exposed schools this didn't result in higher or lower total exposure to noise.

Table 12 Table of $L_{Aeq,1hr}$ personal dosimetry values for subject A and B at each school during the periods 0900 to 1200hrs along with their total $L_{Aeq,3hr}$ exposure

School Code	**School Exposure**		**A**			**B**		**A**	**B**
		9 - 10	***10 - 11***	***11 - 12***	***9 - 10***	***10 - 11***	***11 - 12***	***3hr***	***3hr***
BF	***High***	75.0	87.8	77.5	70.0	86.6	74.1	83.6	82.2
CW	***High***	74.7	83.7	76.5	73.9	81.6	75.9	80.2	78.4
HH	***High***	69.6	88.7	76.8	70.8	90.4	75.3	84.3	86.1
OJ	***High***	67.7	83.4	75.9	76.3	88.8	83.8	79.8	85.7
FJ	***Low***	78.3	86.6	83.8	76.6	85.5	86.4	84.1	84.3
GP	***Low***	75.5	88.4	66.9	69.2	89.9	66.3	84.0	85.4
HJ	***Low***	74.4	84.2	78.0	76.0	85.2	80.4	80.8	82.1
RF	***Low***	75.8	87.2	78.5	74.1	87.9	75.5	83.3	83.6

Actual aircraft movement data

The actual aircraft movement data is based on the Civil Aviation Authority movement data and where possible based on average measured single event levels. For each school an LAeq 8 hr for the 92 days from (04/12/99 – 10/14/99) was calculated (see Table 13) The high noise classified schools ranged from (71- 52 LAeq 8hr) and low noise (0-52 LAeq 8hr). The percentage of school days where levels were equal to or above the average LAeq 8hr ranged in the high noise schools from 26 – 78% and in the low noise schools from 26 – 100%.

Table 13: Actual aircraft movement data

School Code	Outdoor $L_{Aeq,16hr}$	LAeq,8hr	% of school days where levels were equal to or above the average LAeq 8hr
PS	69	71	54
BF	66 - 69	52	26
BP	66 - 69	70	26
GR	66 - 69	54	26
HH	66 - 69	53	26
SJ	66 - 69	64	78
CW	66	52	26
CJ	63 - 66	65	35
OJ	63 - 66	53	45
WP	63 - 66	63	50
BJ	<57	45	26
FJ	<57	48	65
GJ	<57	49	75
GP	<57	0	100
HJ	<57	0	100
JE	<57	49	75
LJ	<57	49	75
NG	<57	52	26
RF	<57	0	100
SG	<57	47	43

3.3 The effects of noise on child cognitive performance: multivariate and multi-level analysis

High and low noise children did not differ in cognitive performance across any of the functions measured: reading; immediate recall; delayed recall; and recognition memory; sustained attention; or serial backward digit recall (see Table 14).

Table 14: Cognitive outcome mean scores age adjusted; fully adjusted for age, deprivation and main language spoken in the 10 high-noise schools, the 10 low-noise schools

Cognitive Outcome Outcome	High Noise Schools Mean (Std Error)	Low Noise Schools Mean (Std Error)	Difference Score (95% Confidence Intervals)	Multi-level Models (Difference Score and Std Error)	F-Statistic, degrees of freedom, P-value
Reading Comprehension					
age adjusted	96.12 (0.79)	95.82 (0.82)	-0.30 [-2.53—1.94]	-0.19 (1.51)	F(1,425)=0.07 P=0.79
age,depri&language adjusted	96.24 (0.78)	95.78 (0.81)	-0.46 [-2.67—1.76]	-0.35 (1.42)	F(1,422)=0.16 P=0.68
Sustained Attention					
age adjusted	8.15 (0.13)	7.93 (0.14)	-0.23 [-0.60—0.15]	-0.22 (0.22)	F(1,424)=1.37 P=0.24
age,depri&language adjusted	8.16 (0.13)	7.92 (0.14)	-0.24 [-0.62—0.14]	-0.23 (0.21)	F(1,421)=1.56 P=0.21
Immediate Recall					
age adjusted	37.11 (1.02)	38.97 (1.03)	1.86 [-1.00—4.72]	1.85 (1.91)	F(1,388)=1.63 P=0.20
age,depri&language adjusted	37.27(1.02)	38.88 (1.03)	1.60 {-1.25—4.46]	1.64 (1.79)	F(1,385)=1.22 P=0.27
Delayed Recall					
age adjusted	31.63 (1.15)	31.21 (1.16)	-0.42 [-3.63—2.80]	-0.36 (2.09)	F(1,388)=0.07 P=0.79
age,depri&language adjusted	31.61 (1.15)	31.20 (1.17)	-0.42 [-3.66—2.82]	-0.28 (2.12)	F(1,385)=0.07 P=0.79
Delayed Recognition					
age adjusted	23.44 (0.25)	23.74 (0.25)	0.31 [-0.39—1.00]	-0.304 (0.403)	F(1,390)=0.75 P=0.38
age,depri&language adjusted	23.47 (0.25)	23.71 (0.25)	0.24 [-0.45—0.92]	-0.236 (0.349)	F(1,387)=0.50 P=0.49
Backward digit span					
age adjusted	3.66 (0.08)	3.61 (0.08)	-0.05 [-0.27—0.16]	-0.06 (0.11)	F(1,427)=0.25 P=0.62
age,depri&language adjusted	3.66 (0.07)	3.62 (0.08)	-0.05 [-0.26—0.17]	-0.05 (0.11)	F=(1,424)=0.17 P=0.67

Note: Chronic noise exposure was not associated with any of these cognitive outcomes after adjustment for mother's education status.

Effect of noise on simple and difficult sub-tests

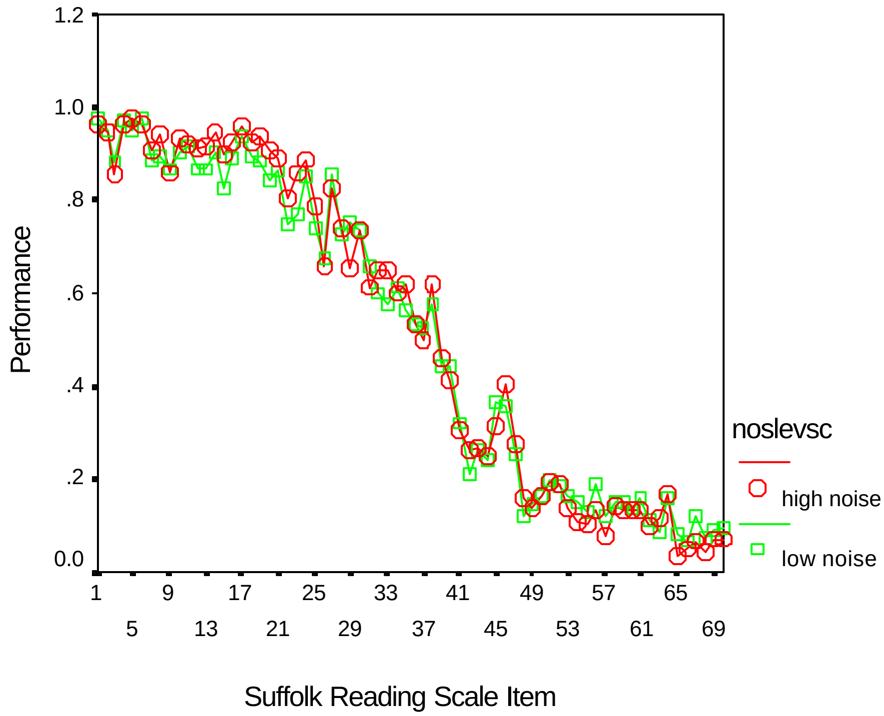
A puzzle in our initial findings on noise and reading comprehension was that the lack of effect we found did not match with the findings from the well-designed Munich

Study (Evans et al, 1995). In the Munich study, noise effects were found only among the most difficult items of the reading test. Professor Staffan Hygge, from the Swedish Royal Institute of Technology, who designed the cognitive tests for the Munich Airport Study visited our team in London in September 2000 to provide expert consultancy on our analysis of the cognitive tests in the West London Schools Study.

He advised us to conduct a repeated measure analysis to test whether high levels of noise exposure affect performance on the more difficult items of the Suffolk reading scale in order to replicate the effects of the Munich Airport Study (Evans et al., 1995). The 70 item Suffolk reading comprehension test is designed so that test items gradually become more difficult. We selected the most difficult 15 items (20% of all items) on basis of the ‘a priori’ test design and empirically on the performance on the whole sample of the most difficult items. A repeated measures multivariate general linear model was run first on all the items and then on the most difficult items on the Suffolk Reading Test (see Figures 1 and 2 below). Noise is the between subjects factor and performance on item is the within-subjects factor. The results for two models will be presented: Model 1, unadjusted, is the data modelled in the figures, and Model 2, adjusted for age, main language spoken and deprivation will be reported in the text for a noise effect. This analysis was repeated on the more difficult items of the other cognitive tests (see Appendix 13).

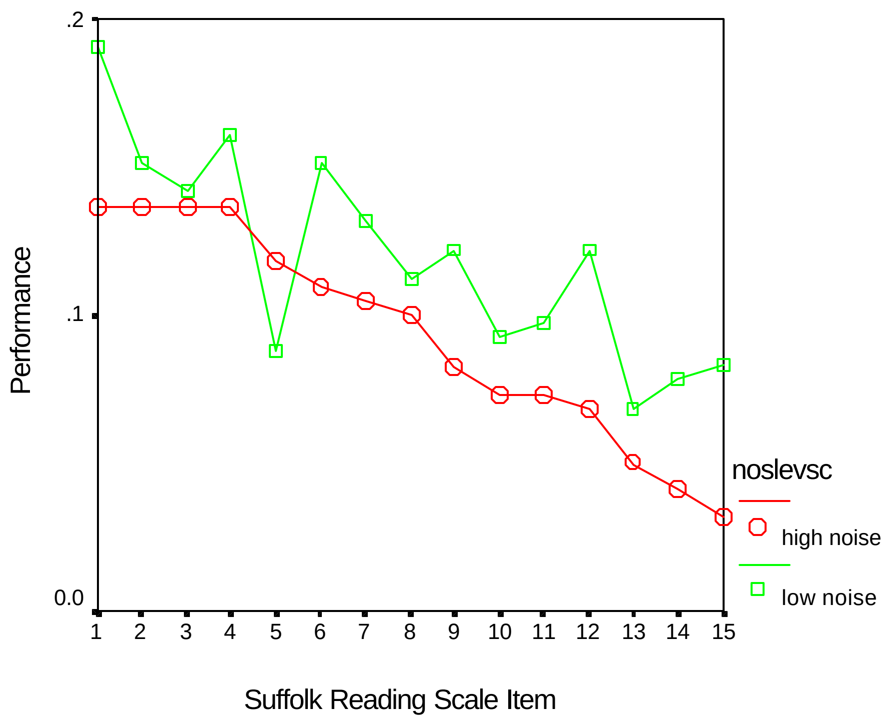
Repeated measures general linear model examining the association between noise exposure on performance on the 70 items of the Suffolk Reading scale did not reveal a significant noise association ($F(1,423)=0.172$, $p=0.679$, figure 1). When this was further adjusted for age, main language and deprivation the effect still remained insignificant ($F(1,417)=0.563$, $p=0.454$).

Fig 1: Repeated measures general linear model examining the association between noise exposure on performance on the 70 items of the Suffolk Reading scale



However the repeated measures general linear model examining the association between noise exposure on performance on the 15 difficult items of the Suffolk Reading scale did reveal a significant noise association ($F(1,423)=4.75$, $p = .030$, figure 2). When this was further adjusted for age, main language and deprivation the effect still remained significant ($F(1,417)=4.75$, $p = .032$). Children in high noise schools had significantly poorer performance than children in the control schools. When this analysis was re-run using multi-level modelling, the same results were obtained and the difference was still significant.

Fig 2: Repeated measures general linear model examining the association between noise exposure on performance on the most difficult 15 items of the Suffolk Reading



3.4 The effects of noise on child annoyance: multivariate and multi-level analysis

Annoyance levels to aircraft noise were significantly higher on both the 5- and 10-point scales among children in the high noise schools compared with the low noise schools (Table 15), after adjustment for age, main language spoken and deprivation. This applied to aircraft noise annoyance both at school and at home. In contrast, levels of annoyance to road traffic noise both at school and at home did not differ significantly across high and low noise schools.

Table 15: Annoyance at school and at home outcome mean scores age adjusted; fully adjusted for age, deprivation and main language spoken in the 10 high-noise schools, the 10 low-noise schools

Annoyance	High Noise Schools Mean (Std Error)	Low Noise Schools Mean (Std Error)	Difference Score (95% Confidence Intervals)	Multi-level Models (Difference Score and Std Error)	F Statistic, DF, p-value
AT SCHOOL					
Aircraft noise annoyance at school (5pt)					
age adjusted	2.20 (0.098)	1.62 (0.10)	-0.586 [-0.86— -0.31]	-0.60 (0.26)	F(1,435)=17.28 P=0.0001
age,depri&language adjusted	2.20 (0.097)	1.65 (0.10)	-0.55 [-0.82— -0.27]	-0.58 (0.26)	F(1,432)=14.92 P=0.0001
Aircraft noise annoyance at school (10pt)					
age adjusted	5.51 (0.25)	4.08 (0.26)	-1.42 [-2.14— -0.71]	-1.43 (0.59)	F(1,434)=15.34 P=0.0001
age,depri&language adjusted	5.50 (0.25)	4.15 (0.26)	-1.35 [-2.07— -0.63]	1.40 (0.60)	F(1,431)=13.55 P=0.0001
Road traffic noise annoyance at school (5pt)					
age adjusted	1.37 (0.10)	1.52 (0.10)	0.15 [-0.13—0.42]	0.12 (0.20)	F(1,435)=1.12 P=0.29
age,depri&language adjusted	1.36 (0.10)	1.53 (0.10)	0.70 [-0.10—0.44]	0.14 (0.20)	F(1,432)=1.52 P=0.21
Road Traffic noise annoyance at school (10pt)					
age adjusted	3.48 (0.24)	3.85 (0.25)	0.37 [-0.33—1.06]	0.30 (0.57)	F(1,435)=1.08 P=0.30
age,depri&language adjusted	3.44 (0.24)	3.88 (0.26)	0.43 [-0.26—1.13]	0.34 (0.56)	F(1,432)=1.50 P=0.22
AT HOME					
Aircraft noise annoyance at home (5pt)					
age adjusted	2.13 (0.10)	1.52 (0.11)	-0.62 [-0.91— -0.32]	-0.66 (0.23)	F(1,434)=16.96 P=0.0001
age,depri&language adjusted	2.14 (0.10)	1.54 (0.11)	-0.60 [-0.89— -0.30]	-0.66 (0.24)	F(1,431)=15.75 P=0.0001

Aircraft noise annoyance at home (10pt)					
age adjusted	5.32 (0.27)	3.66 (0.27)	-1.67 [-2.42— -0.92]	-1.79 (0.54)	F(1,434)=19.08 P=0.0001
age,depri&language adjusted	5.34 (0.27)	3.70 (0.28)	-1.64 [-2.40— -0.87]	-1.75 (0.55)	F(1,431)=18.23 P=0.0001
Road traffic noise annoyance at home (5pt)					
age adjusted	1.41 (0.10)	1.55(0.11)	0.14 [-0.15—0.42]	0.14 (0.16)	F(1,437)=0.88 P=0.34
age,depri&language adjusted	1.40 (0.10)	1.57 (0.10)	0.18 [-0.11—0.46]	0.17 (0.15)	F(1,434)=1.46 P=0.22
Road Traffic noise annoyance at home (10pt)					
age adjusted	3.36 (0.26)	3.95 (0.27)	0.59 [-0.13—1.32]	0.60 (0.37)	F(1,433)=2.58 P=0.10
age,depri&language adjusted	3.31 (0.26)	4.01 (0.27)	0.71 [-0.02—1.40]	0.71 (0.37)	F(1,430)=3.64 P=0.05

3.5) Noise effects in sub-groups of children: stratified analyses

Planned stratified analyses were conducted to test whether the size of the reading or annoyance effect differed within subgroups (2 way interaction).

Reading

For reading, there was no difference in the size of the noise effect between: boys and girls; white and non-white; English and Non-English as the main language spoken at home; children in employed and unemployed households; and children in deprived and not deprived households (see Table 16). There was a main effect of parental employment (employed mean=97.42, low noise mean=90.83, $F(1,420)=23.71$, $p=0.0001$) and deprivation (not deprived mean=98.01, deprived mean=92.70, $F(1,420)=21.08$, $p=0.0001$) on reading performance.

Annoyance

For annoyance, there was no difference in the size of the noise effect between: boys and girls; white and non-white; English and Non-English as the main language spoken at home; children in employed and unemployed households; and children in deprived and not deprived households (see Table 17). There was a main effect of race (white mean=1.57, non-white mean=2.20, $F(1,432)=14.10$,$p=0.0001$) and main language spoken (English mean=1.78, non-English mean=2.19, $F(1,420)=21.08$,$p=0.0001$) on annoyance.

Table 16: reading comprehension mean scores in the high-noise schools and the low-noise schools stratified by sex, race, main language spoken and employment status

Reading Comprehension	High Noise Reading Mean, Sample size (N), (95% Confidence Intervals)	Low Noise Reading Mean, Sample size (N), (95% Confidence Intervals)	Interaction p-value
Girls			
N=215	97.29 (N=114) [95.14—99.44]	95.94 (N=101) [93.66—98.23]	
Boys			
N=211	94.97 (N=106) [92.74—97.20]	95.26 (N=105) [93.38—97.86]	P=0.379
White			
N=188	96.72 (N=76) [94.09—99.36]	96.47 (N=112) [94.30—98.65]	
Non-white			
N=238	95.88 (N=144) [93.97—97.80]	94.95(N=94) [92.58—97.32]	P=0.769
English			
N=276	96.63 (N=131) [94.63—98.64]	96.52 (N=145) [94.62—98.43]	
Non-English			
N=149	95.49 (N=89) [93.06—97.93]	93.97 (N=60) [91.00—96.93]	P=0.556
Employed			
N=334	97.75 (n=169) [96.02—99.47]	97.08 (n=165) [95.33—98.82]	
Unemployed			
N=90	91.18 (n=50) [88.01—94.35]	90.40 (n=40) [86.86—93.94]	P=0.967
Not deprived			
N=256	98.74 (n=136) [96.82—100.67]	97.23 (n=129) [95.26—99.21]	
Deprived N=159	92.16 (n=83) [89.70—94.62]	93.3 (n=76) [90.73—95.88]	P=0.247

Table 17: aircraft noise annoyance mean scores on the 5pt scale in the high-noise schools and the low-noise schools stratified by sex, race, main language spoken and employment status.

Aircraft noise annoyance at school	**High Noise** **Annoyance Mean, Sample size (N), (95% Confidence Intervals)**	**Low Noise** **Annoyance Mean, Sample size (N), (95% Confidence Intervals)**	**Interaction p-value**
Girls			
N=214	2.08 (N=114) [1.81—2.35]	1.62 (N=100) [1.33—1.91]	
Boys			
N=222	2.34 (N=112) [2.07—2.61]	1.60 (N=110) [1.33—1.88]	P=0.319
White			
N=195	1.83 (N=81) [1.51—2.14]	1.39 (N=114) [1.13-1.66]	
Non-white			
N=241	2.42 (N=145) [2.19-2.66]	1.86(N=96) [1.58—2.15]	P=0.662
English			
N=284	2.11 (N=137) [1.87—2.35]	1.48 (N=147) [1.24—1.71]	
Non-English			
N=151	2.36(N=89) [2.06—2.66]	1.95 (N=62) [1.59—2.32]	P=0.448
Employed			
N=340	2.20 (n=173) [1.98—2.42]	1.62 (n=167) [1.40—1.85]	
Unemployed			
N=94	2.27 (n=52) [1.87—2.67]	1.6 (n=42) [1.51—2.04]	P=0.783
Not deprived			
N=266	2.18 (n=138) [1.94—2.43]	1.52 (n=128) [1.26—1.77]	
Deprived N=168	2.28 (n=87) [1.97—2.58]	1.78 (n=81) [1.46—2.10]	P=0.562

3.6 The effects of noise on child stress and health: multivariate and multi-level analysis

Child Self-Reported Health

There was no evidence that these self-reported measures of general physical health were influenced by aircraft noise exposure. Mean levels of self reported general health and three types of child self-reported symptoms plausibly related to noise exposure (headaches, tiredness, and sleeping problems) showed very little difference across children from high and low noise schools. In fact, against expectation, tiredness in the last two weeks was more frequent among children from low noise schools (Table 18).

Table 18: Self reported health: Mean scores across high and low noise schools

Self reported Health	**High Noise Schools Mean**	**Low Noise Schools Mean**	**F statistic, df, and p-value**
Self reported general health	1.63	1.63	F(1,443)=0.004 P=0.95
Headaches in the last 2 weeks	1.97	1.90	F(1,443)=0.96 P=0.33
Tiredness in the last 2 weeks	2.00	2.15	F(1,444)=4.49 P=0.035
Sleeping Problems in the last 2 weeks	1.81	1.92	F(1,444)=1.91 P=0.17

Parent report on child health

Parental reporting on their child’s general health status did not differ between the two groups (high noise mean= 2.88, low noise mean= .05, p=0.07). Nor did parental reporting on other specific health conditions differ between children in high and low noise schools, these included: sleeping difficulties; hearing; asthma and other respiratory health functions; and longstanding illness (see Table 19).

Table 19: Parental reporting on child health: frequencies and proportions, continuity correction chi-square p=value

Parent report on child Health		**High Noise Schools**	**Low Noise Schools**	**P=value**
Sleeping difficulty	No	40.1% (143)	36.4 % (130)	
	Yes, mild	10.9% (39)	11.5% (41)	
	Yes, severe	0.3% (1)	0.8% (3)	P=0.47
Hearing difficulty	No	48.3% (174)	47.5% (171)	
	Yes	2.5% (9)	1.7% (6)	P=0.46
Doctor diagnosed asthma	No	49.9% (142)	38.2% (136)	
	Yes	11.5% (41)	10.4% (37)	P=0.17
Long standing illness	No	45.7% (161)	42.3% (149)	
	Yes	5.1% (18)	6.8% (24)	P=0.26

Child Perceived Stress and Mental Health (SDQ))

High and low noise children did not differ in perceived stress, as rated on the Lewis Child Stress Scale. Children in low noise exposed schools reported more stressful life events than children in the high aircraft noise schools, after adjustment for age, main language spoken and deprivation.

On the Strengths and Difficulties Questionnaire, children in high noise schools had higher total deviance scores than children in low noise schools, which was marginally significant after adjustment for age, main language spoken and deprivation. The high noise children also had higher rates of hyperactivity than the low noise children after adjustment for age, main language spoken and deprivation. Aircraft noise exposure was related to higher prevalence of symptoms of hyperactivity as measured by scores above the clinically relevant cut off points of the SDQ (35.5% high noise abnormal/borderline, 22.1% low noise abnormal/borderline, p=0.006). Aircraft noise exposure was not related to higher prevalence of symptoms of total psychological difficulties, emotional symptoms, conduct problems, and peer problems as measured by scores above the clinically relevant cut off points of the SDQ.

Table 20 Mean health outcome scores adjusted for age, fully adjusted for age, deprivation and main language spoken in the 10 high-noise schools, the 10 low-noise schools

Health	High Noise Schools Mean (Std Error)	Low Noise Schools Mean (Std Error)	Difference Score (95% Confidence Intervals)	F Statistic, DF, p-value
Perceived Stress			0.11	F(1,435)=2.53
age adjusted	3.57 (0.05)	3.67 (0.05)	[-0.03—0.24]	P=0.11
age,depri&language adjusted	3.57 (0.05)	3.67 (0.05)	0.10 [-0.04—0.23]	F(1,432)=2.07 P=0.15
Stress events frequency			0.11	F(1,433)=4.16
age adjusted	2.03 (0.04)	2.14 (0.04)	[0.04. —0.22]	P=0.04
age,depri&language adjusted	2.03 (0.04)	2.14 (0.04)	0.11 [-0.01—0.22]	F(1,430)=3.78 P=0.05
SDQ – conduct			-0.19	F(1,343)=0.95
age adjusted	1.99 (0.14)	1.81 (0.14)	[-0.56—0.19]	P=0.33
age,depri&language adjusted	1.20 (0.13)	1.80 (0.13)	-0.19 [-0.56—0.18]	F(1,343)=1.07 P=0.30
SDQ - peer			-0.14	F(1,343)=0.49
age adjusted	2.15 (0.14)	2.01 (0.14)	[-0.53—0.25]	P=0.48
age,depri&language adjusted	2.13 (0.14)	2.03 (0.14)	-0.11 [-0.49—0.27]	F(1,343)=0.30 P=0.58
SDQ – hyperactivity			-0.66	F(1,343)=10.56
age adjusted	4.81 (0.14)	4.14 (0.14)	[-1.07— -0.262]	P=0.001
age,depri&language adjusted	4.80 (0.14)	4.15 (0.14)	-0.65 [-1.06—-0.25]	F(1,343)=10.28 P=0.001
SDQ – emotional			-0.18	F(1,343)=0.60
age adjusted	2.61 (0.16)	2.43 (0.16)	[-0.63—0.27]	P=0.43
age,depri&language adjusted	2.58 (0.16)	2.46 (0.16)	-0.13 [-0.57—0.32]	F(1,343)=0.31 P=0.58
SDQ – total			-1.17	F(1,343)=3.92
age adjusted	11.56 (0.42)	10.39 (0.42)	[-2.32— -0.08]	P=0.04
age,depri&language adjusted	11.51 (0.40)	10.43 (0.40)	-1.08 [-2.20—0.04]	F(1,343)=3.59 P=0.06

Catecholamines

The analyses, without adjustment for creatinine, demonstrated that children in low noise schools had higher levels of overnight 12 hour secretion of noradrenaline and adrenaline (see Table 21) and there was no difference between the groups in cortisol secretion. When these hormone levels were further adjusted for creatinine the high and low noise children did not differ in overnight 12 hour secretion of noradrenaline, adrenaline and cortisol (see Table 21 for the creatinine ratio).

Table 21: Noradrenaline, adrenaline and cortisol with creatinine ratio outcome mean scores (standard errors) age adjusted; adjusted for age, deprivation and main language spoken in 8 high-noise schools and the 8 low-noise schools

Catecholamines	High Noise Schools Mean (Std Error) N=96 Nmol/µmol	Low Noise Schools Mean (Std Error) N=108 nmol/µmol	Difference Score (95% Confidence Intervals)	F Statistic, DF, p-value
Adrenaline			0.001	F(1,197)=6.15
age adjusted	0.002 (0.003)	0.003 (0.003)	[0.002. —0.002]	P=0.01
age,depri&language adjusted	0.002 (0.003)	0.003 (0.003)	0.001 [0.003—0.002]	F(1,197)=6.77 P=0.01
Noradrenaline			0.003	F(1,197)=3.80
age adjusted	0.17 (0.01)	0.21 (0.01)	[-0.04—6.86]	P=0.05
age,depri&language adjusted	0.17 (0.01)	0.21 (0.01)	-0.003 [-0.003—0.007]	F(1,197)=3.83 P=0.05
Cortisol			6.16	F(1,197)=0.43
age adjusted	92.23 (6.82)	98.38 (6.48)	[-12.46—24.74]	P=0.51
age,depri&language adjusted	92.54 (6.86)	98.10 (6.51)	9.51 [-13.19—24.32]	F(1,197)=0.34 P=0.56
Creatinine			0.95	F(1,197)=2.89
age adjusted	8.10 (0.40)	9.05 (0.38)	[-0.15—2.05]	P=0.09
age,depri&language adjusted	8.13 (0.41)	9.03 (0.40)	0.90 [-0.21—2.01]	F(1,197)=2.55 P=0.11
Adrenaline/creatinine			0.49	F(1,197)=11.5
age adjusted	3.70 (0.40)	4.18 (0.38)	[-0.61— 1.58]	8 P=0.38
age,depri&language adjusted	3.70 (0.40)	4.18 (0.38)	0.48 [-0.62—1.59]	F(1,197)=0.76 P=0.38
Noradrenaline/ creatinine			1.72	F(1,197)=1.21
age adjusted	21.57 (1.13)	23.28 (1.07)	[-1.36—4.79]	P=0.27
age,depri&language adjusted	21.52 (1.13)	23.33 (1.07)	1.80 [-1.28—4.90]	F(1,197)=1.33 P=0.25
Cortisol/ creatinine			-0.65	F(1,197)=0.49
age adjusted	12.00 (0.67)	11.35 (0.64)	[-2.49—1.19]	P=0.48
age,depri&language adjusted	11.98 (0.68)	11.36 (0.65)	-0.62 [-2.48—1.23]	F(1,197)=0.44 P=0.51

3.7) Health effects of noise on parents and teachers

Parents

Parents of children in high noise schools had higher levels of aircraft noise annoyance than parents of children in low noise schools. Parents of children in high noise schools also reported high levels of road traffic annoyance on the 5pt scale, but not on the ten point scale (see table 22). The two groups did not differ in levels of annoyance for rail and neighbours, nor did they differ in levels of general health and perceived stress (see table 22).

Table 22: Mean health outcome scores for parents of children in the high-noise schools and parents of children in the low-noise schools

Health Outcome	High Noise Mean St. Error	Low Noise Mean St. Error	Difference Score (95% Confidence Intervals)	p-value
Aircraft noise annoyance (5pt)	2.04 (0.08)	0.56 (0.09)	-1.48 [-1.71— -1.24]	F(1,355)=151.78 P=0.0001
Aircraft noise annoyance (10pt)	5.24 (0.22)	1.49 (0.23)	-3.75 [-4.38—-3.13]	F(1,353)=140.22 P=0.0001
Road traffic noise annoyance (5pt)	0.84 (0.07)	0.58 (0.08)	-0.25 [-0.46— -0.05]	F(1,356)=5.83 P=0.01
Road Traffic noise annoyance (10pt)	2.35 (0.19)	1.93 (0.20)	-0.42 [-0.96—0.12]	F(1,353)=2.38 P=0.12
Rail noise annoyance (5pt)	0.18 (0.06)	0.27 (0.06)	0.09 [-0.06—0.25]	F(1,345)=1.47 P=0.22
Rail noise annoyance (10pt)	0.40 (0.13)	0.80 (0.14)	0.41 [0.03 —0.78]	F(1,347)=4.50 P=0.03
Neighbours noise annoyance (5pt)	0.69 (0.07)	0.64 (0.07)	-0.04 [-0.24—0.16]	F(1,357)=0.16 P=0.68
Neighbours noise annoyance (10pt)	1.88 (0.19)	1.86 (0.19)	-0.02 [-0.55—0.52]	F(1,351)=0.003 P=0.95
General Health	2.48 (0.07)	2.60 (0.07)	0.12 [-0.07—0.32]	F(1,346)=1.54 P=0.21
Cohen Perceived stress	15.73 (0.46)	16.15 (0.47)	0.42 [-0.88—1.72]	F(1,349)=0.40 P=0.52

Teachers

Teachers of children in high noise schools had higher levels of aircraft noise annoyance than teachers of children in low noise schools (see table 23). The two groups did not differ in road traffic annoyance and rail annoyance**.** The two groups did not differ in levels of general health and perceived stress (see table 23).

Table 23: health outcome mean scores adjusted in the high-noise schools and the low-noise schools

Health Outcome	**High Noise Mean St Error**	**Low Noise Mean St.Error**	**Difference Score (95% Confidence Intervals)**	**p-value**
Aircraft noise annoyance (5pt)	2.21 (0.31)	0.80 (0.37)	-1.41 [-2.42— -0.41]	F(1,23)=8.57 P=0.008
Aircraft noise annoyance (10pt)	5.73 (0.77)	1.80 (0.94)	-3.93 [-6.44— -1.43]	F(1,24)=10.54 P=0.004
Road traffic noise annoyance (5pt)	0.53 (0.16)	0.10 (0.19)	-0.43 [-0.95— -0.08]	F(1,24)=3.00 P=0.09
Road Traffic noise annoyance (10pt)	1.60 (0.47)	0.40 (0.58)	-1.20 [-2.74— 0.36]	F(1,24)=2.62 P=0.12
Rail noise annoyance (5pt)	0.14 (0.18)	0.30 (0.21)	0.16 [-0.42—0.73]	F(1,23)=0.32 P=0.58
Rail noise annoyance (10pt)	0.36 (0.52)	0.90 (0.62)	0.54 [-1.14 —2.22]	F(1,23)=0.45 P=0.50
General Health	2.60 (0.20)	2.70 (0.24)	0.001 [-0.55—0.75]	F(1,24)=0.10 P=0.75
Cohen Perceived stress	16.93 (1.40)	14.00 (1.71)	2.20 [-7.49— 1.62]	F(1,24)=1.78 P=0.19

4. DISCUSSION

The objective of this study was to test whether the noise effects previously found in children are attributable to aircraft noise exposure after adjustment for confounding factors, both at the school and individual level, and to examine variation in the size of noise effects to identify vulnerable sub-groups of children. The results of this study confirm the results from previous studies because noise exposure was associated with impaired reading and raised annoyance. There was no variation in the size of the noise effects in sub-groups of children. The results of this study do not confirm all aspects of previous studies because high levels of noise exposure were not associated with impairments in memory and attention, nor raised catecholamine secretion or self-reported stress.

Summary of findings

1) Aircraft noise exposure was associated with poorer reading performance on difficult items after adjustment for age, main language spoken and social deprivation at the individual and school level. Aircraft noise was not associated with poorer performance on memory, sustained attention or overall reading score.

2) Aircraft noise exposure was associated with raised annoyance after adjustment for age, main language spoken and social deprivation at the individual and school level.

3) Aircraft noise was weakly associated with hyperactivity and psychological morbidity after adjustment for age, main language spoken and social deprivation at the individual and school level.

4) Aircraft noise was not associated with perceived stress, stressful life events nor raised catecholamine or cortisol secretion.

5) There was no evidence that noise effects were larger in subgroups of children, specifically those from areas of high social disadvantage and those with English as an additional language.

6) In parents and teachers, aircraft noise exposure was associated with annoyance. In parents and teachers, aircraft noise was not associated with poorer general health or perceived stress.

The effects of noise on child cognitive performance

The results of this study partly confirm hypothesis 1 *"Chronic aircraft noise exposure produces cognitive impairments in reading comprehension, sustained attention and long term memory recall after adjustment for confounding factors. No effects are expected on the control cognitive outcomes: recognition and working memory. It is hypothesised that chronic noise exposure will have a larger effect on difficult cognitive tests compared with simple tests."* The reading results in the West London Schools Study replicate the results from the Munich Airport Study, where they found that children from noise exposed communities had: i) more errors on a difficult text subscale of a German standardised reading test than children from quiet communities; and ii) the two groups did not differ on the easy and intermediate portions of the test (Evans et al., 1995).

Theory to account for the effect of noise on difficult cognitive tasks effects

The effects of noise on complex cognitive tasks have been attributed to increased arousal and decreased attention, through distraction and decreased focusing on stimuli peripheral to the task, as well as altering choice of task strategy (Stansfeld *et al.*, 2000). Because complex tasks require more attention than simple tasks, researchers argue that noise affects performance on complex tasks more than simple tasks. The Yerkes-Dodson inverse U shaped function between arousal and performance/learning (Yerkes & Dodson, 1908) suggests that because noise is arousing it will facilitate performance on simple tasks, up to a point. However, high levels of arousal interfere with performance on complex tasks, and extremely high levels of arousal interfere with performance on simple tasks. The performance data, which demonstrate that complex tasks such as memory, reading, and problem-solving abilities and not simple cognitive tasks (recognition and short-term memory) are affected by noise, are consistent with this explanation (Cohen et al., 1986; Enmarker *et al.,* 1998; Evans et al., 1995, 1998; Evans & Lepore, 1993; Hygge, 1994; Meis *et al.*, 1998; Smith & Broadbent, 1992; Smith & Jones, 1992).

Memory and Attention

Our cognitive data reveal a mixed pattern of results, that is somewhat comparable to the Munich Airport Study and our previous study around Heathrow Airport - the Schools Environment and Health Study (Haines et al., in press a, in press b). We found no association between noise exposure and our cognitive control outcomes; recognition and working memory measured by the backwards digit recall task, in keeping with the Munich Study (Evans et al., 1995) and our previous study around Heathrow (Haines et al., in press a). However, not confirming Hypothesis 1, we did not find an effect on long term memory recall measured by a test adapted from the Child Memory Scale (Cohen, 1997) and Sustained Attention measured by the Score test from the Tests of Everyday Attention for Children (TEACh, Manly et al., 1998).

These results do not replicate the effect of noise on memory found in the Munich Study (Evans et al., 1995) using a test that was designed to be similar to the Munich test and adapted from a standardised scale. Even though the long term memory test from the Child Memory Scale is known to be a reliable and valid measure of child long term memory, it is possible that this memory test was not designed to be sensitive or difficult enough to detect a noise effect on a more complex recall task. Additionally, it is also possible that performance of delayed recall was enhanced by a priming effect of having conducted the immediate recall task straight after stimulus presentation. This priming could have been caused by immediate rehearsal of stimulus material that is known to improve performance on a delayed task. On balance, given the strength of the previous studies these negative results do not undermine previous findings on memory, however, given the strength of our test they do suggest that the Munich memory effects need to be replicated.

The finding that noise exposure was not associated with sustained attention does not replicate the attention effect found in The Schools Environment and Health Study

(Haines et al., in press b). This negative result is unlikely to be an artifact of poor measurement because the SCORE test administered in this study was the same sustained attention test used in The Schools Environment and Health Study. Previous experimental studies and field studies have yielded equivocal attention results. Nine studies have reported deficits in sustained attention and visual attention associated with noise exposure (Haines *et al.,* 1998; Hambrick-Dixon, 1986; Hambrick-Dixon, 1988; Heft, 1979; Karsdorff & Klappach, 1968; Kyzar, 1977; Moch-Sibony, 1984; Muller et al., 1998; Sanz *et al.,* 1993). However, the evidence from most of these studies is limited because of serious methodological flaws. These flaws include: data were not provided to indicate how well socio-economically matched the noise exposed children were to the control sample (Karsdorf & Klappach, 1968; Kyzar, 1977; Heft, 1979); the sample size was not large enough (most of the studies); there werenot enough schools to rule out a school effect confounding the results (Haines *et al.,* 2000b; Sanz *et al.,* 1993); the statistical methods used were not sensitive enough (Sanz *et al.,* 1993); it was unclear as to precisely what aspect of attention was being measured (cross-out letters, Hambrick-Dixon 1986; visual stimulus detection with verbal or key press response, Hambrick-Dixon 1988); and most of these studies were cross-sectional.

In contrast to the methodologically weak studies where positive attention results have been found, Evans and colleagues (1995), in a longitudinal prospective study did not find that chronic noise exposure was associated with poorer attention performance on an embedded figures task. In the present study, the attention analyses were adjusted for potential confounding factors including age, main language spoken at home, parental educational attainment and composite indices of social deprivation and used multi-level modelling to take into account school level as well as individual level factors. Taking the negative result from the West London Schools study in the context of the Munich Study it can be concluded that the research to date does not provide a clear confirmation that noise affects child attentional processes.

Mechanisms and moderators for cognitive effects

We aimed to test whether other environmental factors including length of time exposed to aircraft noise, home noise exposure and crowding at home moderate the association between aircraft noise exposure and cognitive impairments. This was not possible because school noise exposure was highly correlated with home noise exposure. There was very little variation within the high noise sample for length of time exposed to noise, so it was not possible to test for an interaction. It was also planned to test the potential mediating effects of sustained attention on the reading effect but this was not possible because we did not find a main effect of noise on mean reading score or sustained attention.

Further research is needed to establish the mechanisms of the reading effect. Difficulties in attention, communication difficulties, interference with speech perception and learned helplessness have all been proposed as possible mechanisms for noise induced cognitive impairments. The most theoretically plausible hypothesis for which there is empirical evidence suggests that the relationship between noise exposure and cognitive impairments is partially mediated by language acquisition, specifically speech perception processes (Evans & Maxwell, 1997).

Effect of noise within subgroups

It is possible that noise effects could be explained by higher levels of social disadvantage in noise exposed areas. In this case, noise exposure could be merely an indicator of the real factor causing impaired school performance, namely social deprivation. But the association may be more complex than this; aircraft noise exposure may be one of the many ways in which the effects of social disadvantage and health are mediated, noise is thus part of the explanation why social disadvantage influences health. This may have implications for matching schools by level of social disadvantage. If noise exposure contributes to social disadvantage then selecting schools in low noise to match with high noise school on social disadvantage, may mean choosing generally less advantaged low noise schools, constituting over adjustment. Alternatively, social disadvantage and noise exposure may have independent effects on school performance with the possibility that noise moderates the effects of social disadvantage on health.

It was anticipated that children living in families with high levels of social disadvantage would be more vulnerable to the effects of noise. This led to the examination of noise within subgroups of more and less disadvantaged children. This suggested a model in which multiple stressors might have additive or even multiplicative effects on children's cognition and health. This was not confirmed.

Noise exposure, school quality and social deprivation

As well as possible noise effects, cognitive performance is also influenced by school quality, which may confound noise effects. Even among primary schools from relatively socially homogenous areas, schools may differ according to quality of head teachers, teachers' morale, organisation and educational results. By increasing the number of schools and children relative to the previous study around Heathrow Airport, the aim of the study was to test whether the noise effects on annoyance and school performance previously found in children were attributed to noise or whether the effects could have been explained by school quality. Analysis of school level factors using multi-level modelling had very little impact on the association between aircraft noise exposure, cognitive performance and health, suggesting that differences between individual primary schools did not explain noise effects.

Noise Annoyance

The results of the study confirmed Hypothesis 2 that "*Chronic aircraft noise exposure in school children will be associated with higher levels of annoyance by noise than children in schools exposed to lower levels of aircraft noise after adjustment for confounding factors*". Children from high noise schools both heard more aircraft noise and were more annoyed by it than children from low noise exposed schools. These results have added validity because their perceptions and their annoyance levels in relation to road and rail traffic did not differ much across high and low aircraft noise exposed schools. These results replicate the earlier findings from the Schools Health and Environment Study (Haines et al, in press a, in press b) and other studies (Bronzaft & McCarthy, 1975; Evans et al., 1995).

The mean response of children in high noise schools, was that aircraft noise at school annoyed them 'quite a bit' compared with the children from the low noise schools whose mean response was 'a little'. We explored this annoyance response in qualitative interviews in a subsample of the high noise and control children to provide more in-depth comparative information about the annoyance reaction (Haines, Brentnall & Stansfeld, 2000). The results from the individual interviews indicate that the emotional response that children exposed to high levels of aircraft noise expressed was 'bothered', 'angry' and 'stressed out' which is consistent with the definition that annoyance involves mild irritation, fear and anger (Cohen & Weinstein, 1981). The results from the individual interviews also indicated that perception of noise exposure and the extent to which it disturbed child activities was linked to actual exposure. Children in schools exposed to high levels of aircraft noise reported being less satisfied with their environments in general than children in schools exposed to lower levels of aircraft noise around Heathrow airport. In particular, they felt more disturbed and stressed by aircraft noise compared with the control sample. It is interesting to note that some children in low noise schools report mild aircraft interference when in the playground and at home when doing homework. This is because it is possible for children in low noise exposed schools to also be exposed to some aircraft noise exposure (For full results of this qualitative sub-study see Haines, Brentnall and Stansfeld, 2000).

The stratified analyses indicate that even though there was no variation in the size of the noise annoyance effect within sub-groups, there was a main effect of annoyance on the basis of ethnicity. Children who were non-white and had non-English as the main language spoken at home reported higher levels of noise annoyance. This may indicate that different cultural groups have different sensitivities to noise exposure that may account for the difference in noise annoyance.

It is not clear whether high levels of aircraft noise annoyance in children have longer term health implications, but certainly they seem to be an indication of short term disturbance of quality of life. The next step for future research is to examine the dose-response relationship between aircraft noise exposure and child annoyance with a standardised child annoyance scale. This is one of the objectives of the RANCH project (Road Traffic and aircraft noise exposure and children's cognition and health: exposure-effect relationships and combined effects), commissioned by the European Commission under the 5th Framework that is being co-ordinated by Queen Mary, University of London (Start Date: January 2001 End Date: December 2003).

Self-reported Health, Mental Health, Self-Reported Stress

The results of this study did not support Hypothesis 3*"Chronic aircraft noise exposure in school children will be associated with higher levels of self-reported stress than children in schools exposed to lower levels of aircraft noise. No effects are expected on the mental health outcomes."* Consistent with previous studies, aircraft noise exposure in the West London Schools Study does not seem to influence simple measures of self-reported symptoms and overall health. Contrary to the Schools Environment and Health Study (Haines et al., in press b), there was no difference in perceived stress between the groups. The children in the low noise exposed schools reported having experienced more stressful life events than the children in the high noise schools. This difference in life experience, where the low noise sample had experienced more stressful life events in their lives, might account for the lack of noise effects on perceived stress. In Munich, children living in the noisy environment had lower psychological well-being than children living in quieter environments (Evans *et al.,* 1995). The longitudinal data from around Munich show that, after the inauguration of the new airport, the newly noise-exposed communities show a significant decline in self-reported quality of life, after being exposed to the increased aircraft noise exposure for 18 months (third wave of testing), compared with a control sample (Evans *et al.,* 1998). The effect of aircraft noise and child psychological well-being and perceived stress needs to be examined in future research to explain the discrepancy between the Munich Study and the Schools Environment and Health

Study where an association was found and these results from the West London Schools Study. Adaptation to noise and comparison with environmental quality before the new airport opened in Munich may be important factors here.

Unexpectedly, aircraft noise was weakly associated with hyperactivity and psychological morbidity as measured by the Strengths and Difficulties Question after adjustment for age, main language spoken and social deprivation at the individual and school level. These mental health results are not consistent with the Schools Environment and Health Study where chronic aircraft noise exposure was not associated with anxiety and depression (measured with psychometrically valid scales) and total SDQ score after adjustment for socio-economic factors in the Heathrow study (Haines et al., 2000b). In this study there was no evidence that high SDQ score is associated with higher annoyance, replicating the Schools Environment and Health Study (Haines & Stansfeld, 2000). Aircraft noise exposure was also related to higher prevalence of symptoms of hyperactivity as measured by scores above the clinically relevant cut off points of the SDQ. This hyperactivity finding is consistent with arousal theory of the effects of environmental stressor influencing child health and performance (Cohen et al., 1986). According to arousal theory noise exposure changes arousal level, which may led on to raised activity level, that might become manifest as chronic hyperactivity. Given that aircraft noise was only weakly associated with psychological morbidity and that it is not consistent with previous studies, this effect needs to be replicated before a definite conclusion can be drawn.

Catecholamines

Contrary to expectation, there was an association between adrenaline and noradrenaline in the control sample exposed to low levels of aircraft noise. The low noise group had significantly higher levels of noradrenaline and adrenaline after adjustment for age, main language spoken at home and deprivation. However, there was no association between noise exposure and catecholamine secretion after adjustment for creatinine level. Hormone/creatinine ratio has been proven by White and colleagues (1995), to be a more reliable measure of endocrine secretion than a hormone value on its own. The lack of an association between cortisol levels and noise exposure was consistent with all past cortisol and noise tests carried out (Evans et al, 1995, 1998 Haines et al, in press a) The high level of catecholamines in the low noise control group is consistent with the higher level of self reported stress reported by the control group. However, the negative results could be due to the method of collection. Ascorbic acid was used instead of the normative hydrochloric acid for safety and ethical reasons. This method was not standardised and had been reported in one research report (Al-Maney et al, 1996). Whether noise has any bearing on catecholamine secretion is still an open issue due to the contradiction in results between these results and those of the Munich airport study (Evans et al, 1995, 1998).

Noise exposure

The noise exposure data obtained confirms that the schools classified as high noise were actually exposed to high levels of aircraft noise. For those schools exposed to high noise levels, it would be reasonable to expect there to be an effect on learning and the cognitive performance of the children. At the most simplistic level, interference with speech is possible at some schools, which will clearly impact upon teaching efficiency for some lesson types.

Calculation of internal noise contour values based on the outdoor to indoor level difference proved instructive, enabling ranking of the schools by internal exposure. Although measurements were made of the acute exposure during cognitive testing, this should not necessarily be used to infer levels of chronic exposure. The changing patterns of runway use means that this relationship is complex and the calculated internal exposure based on the external contour values is the best estimate of the long term exposure of the children to aircraft noise in the classroom. The data from the medium term exposure of the high noise schools demonstrating variability of exposure suggest that a contour may not accurately capture the detail of the actual level of aircraft interference and consistency of aircraft interference in these schools.

Noise exposure based on contours is fairly crude; within contours there may be considerable variation based on flight paths and runway alteration.

Internal noise levels in the classroom were often dominated by noise from within the classroom in all but the most highly exposed schools and, in this respect, of particular note, was the poor sound insulation of portacabin style school buildings, especially with open windows. In those schools where good levels of sound insulation were found, provision was often made for ventilation by means other than opening windows, this ensures the benefit of the good sound insulation is available all year. Even though internal levels did differ within high noise schools, analyses conducted on the basis of reclassification of noise exposure did not alter any of the main results (annoyance and reading, see Appendix 12).

A trial was undertaken of the use of dosimetry for measuring the personal noise exposure of children when at school. This demonstrated that personal dosimetry of children was a practical possibility; the devices were robust due to their intended use in industrial workplace environments, the keypad was locked to prevent tampering and with those particular units detailed noise level data was obtained for small time intervals of one second. No problems were perceived in getting the children to wear the units and fitting was straightforward.

The results of the dosimetry sub-sample do not indicate differing personal exposure to noise for children attending high or low aircraft noise exposed schools. The results obtained suggest that dosimetry could play an important role in future assessment of true personal exposure to environmental noise sources when used in conjunction with the more usual microphone locations. This technique allows the assessment of exposure as the subject moves into differing noise environments, in this case for example, when the children were outside.

Parent and teacher effects

The results of the study partly confirm hypothesis 4 **"***Chronic aircraft noise exposure* *in parents and teachers will be associated with higher levels of annoyance by noise and perceived stress than in parents and teachers exposed to lower levels of aircraft noise."* The fact that chronic exposure to aircraft noise was associated with raised annoyance in teachers and parents is entirely consistent with previous adult surveys of noise annoyance in the UK around Heathrow Airport (McKennell, 1963; Griffiths & Langdon, 1968; OPCS, 1971; Tarnopolsky & Morton-Williams, 1980) and other countries (Job, 1988; Fields, 1992). Quantitative relationships have been found between the proportions of teachers bothered by noise and the noise levels to which they are exposed at school (Sargent et al. 1980).

Teacher and parent distraction and annoyance from noise interruptions may have indirect effects on child cognitive development and annoyance because of alterations in parents' and teachers' behaviour (Evans *et al.*, 1991). Noise exposure also affects communication in the classroom, which makes it more difficult for children to learn and teachers to teach and may lead to frustration, interruption in speech and a reduction in instruction time (Bronzaft & McCarthy, 1975; Crook & Langdon, 1974). Crook & Langdon (1974) claimed that the principle changes in observed classroom behaviour around Heathrow Airport resulted from interference with speech. Speech interference jeopardises the continuity and flow of the lessons and is a nuisance that may result in teacher and child frustration. Ko (1979) reported, in a survey of 139 schools in Hong Kong (mean peak aircraft noise level above 70 dBA), that aircraft noise disrupts verbal communication, resulting in speech and teaching interference during lessons and that teachers suffer from noise annoyance. It is possible that environmental noise may affect teachers' and parents' encouragement of children. In this way, noise may affect teachers' and parents' behaviours and may potentially indirectly contribute to the noise effects on children. This account is based on anecdotal evidence which makes it the weakest theory to account for noise related cognitive and health effects in children. It is, however, still possible that 'teacher frustration and communication difficulties' may, in part, mediate the child reading and annoyance noise effects.

Strengths and limitations

In the West London Schools Study, attempts were made to improve on the previous study around Heathrow Airport (Haines et al, in press a and b) and other cross-sectional field studies (Cohen et al., 1980; Evans and Maxwell, 1997) to reduce possible biases related to differences between schools in school quality and general levels of social deprivation. This was achieved by choosing larger numbers of schools, and by careful matching for socioeconomic position between high and low noise exposed schools using eligibility for free school meals as the matching criterion. This seems to have been successful as levels of unemployment and low family income did not differ between high and low noise school children. In addition, we had large enough numbers to conduct stratified analyses examining noise effects within potentially high risk subgroups, but perhaps larger sample sizes are required in future studies. For the first time, multi-level modelling statistical techniques were used in a field study to examine noise effects that enabled us to adjust analytically for the potential confounding effects of school characteristics on associations between noise and performance at the individual level.

Conclusions

The cognitive results from this study provide new evidence concerning the nature of cognitive noise effects. The results indicate that chronic aircraft noise exposure does not always lead to generalised cognitive effects but more selective cognitive impairments in children exposed to chronically high levels of noise exposure (Cohen et al., 1986; Evans et al., 1995; Evans & Cohen, 1987; Wachs & Gruen, 1982). The noise effect on reading confirms previous findings (Evans & Lepore, 1993; Evans et al., 1995, Evans and Maxwell, 1997; Haines et al., in press a and b) that noise exposure is associated with poorer reading performance but that the effects are confined to difficult items and not simple items. Taking the annoyance results of this study together with previous studies in children and adults, it can be concluded that chronic noise exposure is associated with raised noise annoyance in children.

Policy Recommendations and Future Research

1) These results add to the growing research evidence around international airports that chronic high levels of noise exposure affect children's reading and lead to raised annoyance. They further suggest that children in Britain exposed to high levels of aircraft noise at school are being taught in a disadvantaged learning environment that has negative consequences for cognitive development and well-being. These results should be considered when making policy on noise exposure limits, school environments and buildings and when planning future transport developments. In addition, these results have implications not only for UK policy but also European Policy, specifically the Framework Directive on *"The Assessment and Reduction of Ambient Noise"* from DG Environment due in 2006. Appendix 14 lists some of the publications that will arise out of this study that will have implications for policy.

2) The next step for future research is to test for dose-effect relationships between transport noise and children's health and cognitive function. This will allow for the identification of noise thresholds above which noise may have cognitive and health effects. This will provide information so that rational decisions on safe ambient noise levels for EU and UK policy can be made on the basis of empirical evidence.

3) Future studies need to administer cognitive tests that are sensitive enough to detect performance across test items that differ in difficulty. Future research is needed to develop a standardised child noise annoyance scale.

4) Future research is required to assess how noise may affect teachers' and parents' behaviour and annoyance, and how this may potentially, indirectly, contribute to the noise effects on children.

5) When undertaking noise measurements in school studies special consideration must be given to the various methods that can be used to quantify exposure. If personal dosimetry is to be used for assessment of exposure to environmental sources then the facility to record a detailed profile of the time history of noise levels is considered essential. Further research is needed to compare results from static microphones with those from dosimeters worn by children when measuring in the same room.

Acknowledgements

We would like to thank the children, parents and teachers who took part in study. Without their generous participation this research would not have been possible. We would like to acknowledge the scientific consultancy of Professor Staffan Hygge. We would also like to acknowledge the scientific advice of Stephen Turner, Professor Soames Job, Professor Andy Smith, Professor Gary Evans and Professor Birgitta Berglund. This research was conducted working in partnership with the local education and environmental authorities and health agencies around Heathrow Airport. We thank them for supporting our project. We are grateful for the valuable contributions of the school nurses. We would like to acknowledge the contribution of the Clinical Biochemistry Department at Hope Hospital in Salford, Manchester. The West London Schools Study was jointly funded by Department of Health and Departments of the Environment and Transport and the Regions and administered through the MRC Institute for Environment and Health. We thank them for their support of, and assistance with, the research.

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