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The West London Schools Study: the effects of chronic aircraft noise exposure on child health

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ABSTRACT

Background. Previous field studies have indicated that children's cognitive performance is impaired by chronic aircraft noise exposure. However, these studies have not been of sufficient size to account adequately for the role of confounding factors. The objective of this study was to test whether cognitive impairments and stress responses (catecholamines, cortisol and perceived stress) are attributable to aircraft noise exposure after adjustment for school and individual level confounding factors and to examine whether children exposed to high levels of social disadvantage are at greater risk of noise effects.

Methods. The cognitive performance and health of 451 children aged 8–11 years, attending 10 schools in high aircraft noise areas (16 h outdoor Leq > 63 dBA) was compared with children attending 10 matched control schools exposed to lower levels of aircraft noise (16 h outdoor Leq < 57 dBA).

Results. Noise exposure was associated with impaired reading on difficult items and raised annoyance, after adjustment for age, main language spoken and household deprivation. There was no variation in the size of the noise effects in vulnerable subgroups of children. High levels of noise exposure were not associated with impairments in mean reading score, memory and attention or stress responses. Aircraft noise was weakly associated with hyperactivity and psychological morbidity.

Conclusions. Chronic noise exposure is associated with raised noise annoyance in children. The cognitive results indicate that chronic aircraft noise exposure does not always lead to generalized cognitive effects but, rather, more selective cognitive impairments on difficult cognitive tests in children.

INTRODUCTION

Previous studies examining the effects of noise exposure on child health have not been of sufficient size to account adequately for the role of confounding factors in the relationship between noise and cognitive impairments neither have they thoroughly examined the possibility that some children may be more vulnerable to the effect of noise than others (Cohen *et al*. 1980; Evans *et al*. 1995, 1998; Evans & Maxwell, 1997, Haines *et al*. 2001*a*, *b*). This study has been designed to be of sufficient size 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 variations in the size of noise effects to identify vulnerable subgroups of children.

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The most widespread 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). There is empirical evidence from laboratory (Smith & Broadbent, 1992; Smith & Jones, 1992; Hygge, 1994; Enmarker *et al.* 1998; Meis *et al.* 1998) and field studies (Evans *et al.* 1995, 1998) to suggest that complex tasks that involve central processing demands and language comprehension, such as reading, attention, problem-solving and memory are more affected by noise exposure than simple tasks. Apart from the cognitive effects previous research has demonstrated a pattern of physiological and psychological stress responses associated with chronic noise exposure in children. Chronic high levels of noise exposure have been associated with: higher levels systolic and diastolic blood pressure (Cohen *et al.* 1980; Evans *et al.* 1995, 1998; Regecova & Kellerova, 1995); raised catecholamine secretion (Evans *et al.* 1995, 1998); raised annoyance (Bronzaft & McCarthy, 1975; Evans *et al.* 1995; Haines *et al.* 2001 *a*) and lower psychological well-being (Evans *et al.* 1995, 1998; Haines *et al.* 2001 *a*, *b*). However, noise exposure does not seem to be associated with anxiety, depression and psychological morbidity (Haines *et al.* 2001 *a*).

There is still uncertainty as to how much the observed cognitive impairments in our previous field study around Heathrow (Haines *et al.* 2001 *a*, *b*) and other field studies (Cohen *et al.* 1980; Evans *et al.* 1995, 1998) 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 using national standardized test scores confirms this suggestion because noise exposure and social class were found to be inter-related and might act together to influence performance (Haines *et al.* 2001 *c*). Previous research has dealt with this inter-relationship through selecting schools matched on social factors and making statistical adjustment for social factors. This is limited because this method does not address the potential influence of school level factors (e.g. school quality) on performance (Cohen *et al.* 1980; Haines *et al.* 2001 *a*). By applying multi-level modelling statistical techniques in the present study we can test whether school effects 'explain' any of the variation in health and performance between noise exposed areas after adjustment for individual level social factors.

Identifying vulnerable subgroups is an important consideration for strategically targeted policy for those children who area most at risk (Kryter, 1985; Evans & Lepore, 1993). 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. In this study we examined children with high levels of social disadvantage as a group within the child population who may be at higher risk. These were examined in other subgroups of children namely: boys and girls, white and non-white children, those children with and without English as the main language spoken at home.

The 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. It is also hypothesized that the effects of noise exposure on reading and annoyance will be larger in vulnerable groups (socially deprived, those without English as the main language spoken at home).

METHOD

Design

In this cross-sectional epidemiological field study, the school performance and health of children attending 10 schools in a high-aircraft noise-impact urban area (16 h outdoor Leq > 63 dBA) were compared with those of children from 10 matched control schools in low-aircraft noise-impact urban areas (16 h outdoor Leq < 57 dBA) around Heathrow Airport in West London. Schools were chosen within the published 1997 Civil Aviation Authority dBA Leq, 16 h (92 days) contour maps indicating the average continuous equivalent sound level of aircraft noise within a particular area for 16 h daily periods. The schools were initially chosen such that children were matched across high and low aircraft noise: age; sex; and sound level at the school from non-aircraft sources; existing noise protection in the schools; socio-economic status and main language spoken by the pupils at the school. The children were already randomly selected into mixed ability classes. The performance and health measures were group administered in the classrooms. Parents and teachers of all the school children were given a questionnaire to complete. Noise measurements were conducted at the schools to assess aircraft noise exposure during testing at both baseline and follow-up. An overnight urinary sample was collected from a subsample of the children to measure catecholamines and cortisol.

Participants

The participants were 451 fourth grade pupils (mean age = 8 years and 8 months (age range 8 yr 1 mo–9 yr 8 mo, 49 % girls, 51 % boys); 236 attended school in a high-aircraft noise-impact urban area (16 h outdoor Leq > 63 dBA) and 215 attended school in a low-aircraft noise-impact urban area (16 h outdoor Leq < 57 dBA) surrounding Heathrow Airport in West London. Catecholamines were measured in a random subsample of 204 children split between noise exposed (96) and control groups (108). Twenty-five teachers and 361 parents also completed a questionnaire.

Stress response and health outcome measures

Annoyance

Noise annoyance was measured with four child adapted standard questions (Fields *et al.* 1998). These questions assessed the level of annoyance on a 5-point Likert scale felt by the child when they heard aircraft noise and road traffic noise at home and school, in the last 12 months. The higher the score indicated the higher the noise annoyance levels.

Catecholamines and cortisol

A subsample of the study population were tested for 12 hour overnight (8.00 p.m.–8.00 a.m.) urinary catecholamines (adrenaline, noradrenaline) and free unbound cortisol. Catecholamines and cortisol exhibit a circadian rhythm thereby showing a decline in nocturnal secretion. By expressing the catecholamine and cortisol measurements as a stress hormone: creatinine ratio, the need to accurately record the sleep duration in each individual is eliminated (Peatson *et al.* 1996). Sixteen schools (eight high noise and eight low noise) took part. Adrenaline and noradrenaline were assayed using high-performance liquid chromatography (HPLC) with electrochemical detection (Rosano *et al.* 1991) and cortisol was measured using radio-immunoassay (RIA) (Moore *et al.* 1985).

Lewis Child Stress Scale

Child stress was measured with the child stress scale (Lewis *et al.* 1984) previously used in child noise studies (Haines *et al.* 2001*b*). The first scale asks the children to rate how bad would they feel if each of the 20 stress-provoking situations happened to them on a five point scale to produce the perceived stress score. The second scale asks the children to rate how often each of the 20 situations happened to them on a 5-point scale to produce the frequency score. Normative data from 2480 5th grade American students found high internal consistency (alpha = 0·82) (Lewis *et al.* 1984).

Strengths and Difficulties Questionnaire (SDQ)

This parent questionnaire included the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1994) which is designed to detect psychological morbidity in children aged 4–16. The SDQ is composed of 25 items divided into five scales of five items each: hyperactivity, emotional, conduct problems, peer problems and prosocial behavior. The total score is a summation of hyperactivity, emotional, conduct and peer problems subscales. The SDQ questionnaire has equivalent predictive validity to the Rutter Questionnaire (Goodman, 1997) from which it was modified (Rutter *et al.* 1970).

Cognition and performance outcome measures

Reading comprehension

This was measured using the Suffolk Reading Scale (Hagley, 1987) Level 2. The level two Suffolk Reading Scale contains 70 multi-choice questions with four potential answers. 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 Suffolk Reading Scale has been standardized on a large randomly selected and representative racially and socio-economically mixed national sample of primary aged school children. The scale has good construct validity, test–retest reliability and internal consistency (Hagley, 1987) and has been used in previous noise studies (Haines *et al.* 2001 *a*, *b*)

Long-term memory recall and recognition

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 min delay with an interference task. The answers were scored by using a standardized procedure for the Children's Memory Scale (Cohen, 1997). Three scores were calculated: (1) immediate recall; (2) delayed recall; and, (3) recognition scores.

Backward serial digit recall

This test was adapted to group administration from being widely used in children's testing batteries (WISC-III; CMS; The working memory battery Pickering & Gathercole, 2000). Ten trials of two sets of each of these digit sequences: 2, 3, 4, 5, 6 were presented on an audio-cassette. The subjects are timed out for 20 s per trial. A digit span score was calculated as the number of digits in the penultimate trial before the failure.

Sustained attention

This was measured with the Score task taken from Tests of Everyday Attention for Children (TEA-Ch) battery of measures for the assessment of attention in children (version A; Manly *et al.* 1998). In this task, the 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 test has good construct validity and test–retest reliability (76·2%) after 6–15 days re-administration (Manly *et al.* 1998) and has been used in previous noise studies (Haines *et al.* 2001 *b*). There are 10 trials each scored for correct number of items counted.

Measurement of confounding factors

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 (these data were collected from parents). The number of indicators of household deprivation reported out of these seven indices were summed and a total deprivation score calculated (Townsend *et al.* 1989). Household deprivation was preferred as a confounding factor because social class is not considered to be a satisfactory indicator of social disadvantage (Bartley *et al.* 1994). Missing values for deprivation were imputed with the child's eligibility for free school meal status. Also, main language spoken at home was collected from the children, parents and school. Age was collected from school records and the parents.

Procedure

The group administered testing was conducted on one occasion in each of the schools, in the classrooms, controlling for time of day counter-balanced for day of the week across noise exposure. All the teachers and parents of the children who participated in the study were given their questionnaires in the same month as the testing sessions. Aircraft noise exposure levels at each participating child's home were also taken from the 1997 CAA contour maps. Self-reported home and school noise exposure were assessed from four sources of environmental noise (trains, road traffic, planes, neighbour noise).

Statistical procedures

Analyses of covariance (ANCOVA) were used to examine the cross-sectional main noise effects and general linear model (GLM) repeated measures for item analysis in SPSS for windows version 10.0. The multilevel models were fitted to the data using the statistical package, MLn

Table 1. *The sociodemographic characteristics of the high and low noise child samples: percentages and frequencies unless otherwise stated*

Sociodemographic characteristic	High noise N = 236 % (*N*)	Low noise N = 215 % (*N*)	χ^2 continuity corrected *P*
Age			
Mean	8 yrs 8 mo	8 yrs 9 mo	
Range	(8y1m–9y7m)	(8y1m–9y8m)	
Girls	50·4 (119)	47·9 (103)	
Boys	49·6 (117)	52·1 (112)	0·66
White	34·7 (82)	54·0 (116)	
Non-White	65·3 (154)	46·0 (99)	0·01
Main language spoken at home			
English	58·5 (138)	70·1 (150)	
Non-English	41·5 (98)	29·9 (64)	0·01
Mother's education status			
Degree or equivalent	9·1 (16)	9·0 (15)	
A-level and other higher education below degree	21·7 (38)	13·9 (23)	
GSCE/O-level/equivalent	38·3 (67)	44·6 (74)	
No qualifications	30·9 (54)	32·5 (54)	0·28
Not deprived	60·9 (143)	61·2 (131)	
Deprived	39·1 (92)	38·8 (83)	1·000
Crowding	18·4 (32)	18·9 (32)	
Not crowding	81·6 (142)	81·1 (137)	1·000
Non-manual social class	57·2 (79)	43·7 (62)	
Manual social class	42·8 (59)	56·3 (80)	0·03
(Percentage with missing social class)	42 (98)	34 (73)	
Head of household			
In full-time employment	75·7 (178)	79·0 (169)	
Not in full-time employment	24·3 (57)	21·0 (45)	0·48

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 % free school meal. Missing data Race and Main Language were imputed with school record. Deprivation is a scale summation of these indices: income, home tenure, access to car ownership, employment status, central heating, social class, household crowding. Two indices or above indicated deprivation. Continuous variable was entered into ANCOVA models.

(Woodhouse *et al*. 1995). Two models were used in all analyses: 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). Difference scores and standard errors for the age adjusted and fully adjusted multi-level models are also contained in the Tables for the most important results. 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 of health only include the analysis of covariance. All statistical tests are two-tailed and the alpha value was set at 0·05.

RESULTS

Descriptive results

The overall response rate to the study was 82% with no evidence of differential response rates across noise exposure (high noise = 83%, low noise = 81%). Refusal to take part only accounted for just over 5% of the sample. The participating sample was representative of the eligible sample in terms of main language spoken, ethnicity and eligibility for free school meals. The samples were well matched by age and sex. 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 1). Although it was difficult to match on ethnicity across high and low noise areas, as the noise exposed areas east

Table 2. *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	High noise schools Mean (S.E.)	Low noise schools Mean (S.E.)	Difference score (95% CI)	*P*	Multi-level models Difference score (S.E.)
Reading comprehension					
Age adjusted	96·12 (0·79)	95·82 (0·82)	−0·30 (−2·53 to 1·94)	0·79	−0·19 (1·51)
Age, depri&language adjusted	96·24 (0·78)	95·78 (0·81)	−0·46 (−2·67 to 1·76)	0·68	−0·35 (1·42)
Sustained attention					
Age adjusted	8·15 (0·13)	7·93 (0·14)	−0·23 (−0·60 to 0·15)	0·24	−0·22 (0·22)
Age, depri&language adjusted	8·16 (0·13)	7·92 (0·14)	−0·24 (−0·62 to 0·14)	0·21	−0·23 (0·21)
Immediate recall					
Age adjusted	37·11 (1·02)	38·97 (1·03)	1·86 (−1·00 to 4·72)	0·20	1·85 (1·91)
Age, depri&language adjusted	37·27 (1·02)	38·88 (1·03)	1·60 (−1·25 to 4·46)	0·27	1·64 (1·79)
Delayed recall					
Age adjusted	31·63 (1·15)	31·21 (1·16)	−0·42 (−3·63 to 2·80)	0·79	−0·36 (2·09)
Age, depri&language adjusted	31·61 (1·15)	31·20 (1·17)	−0·42 (−3·66 to 2·82)	0·79	−0·28 (2·12)
Delayed recognition					
Age adjusted	23·44 (0·25)	23·74 (0·25)	0·31 (−0·39 to 1·00)	0·38	−0·304 (0·403)
Age, depri&language adjusted	23·47 (0·25)	23·71 (0·25)	0·24 (−0·45 to 0·92)	0·49	−0·236 (0·349)
Backward digit span					
Age adjusted	3·66 (0·08)	3·61 (0·08)	−0·05 (−0·27 to 0·16)	0·62	−0·06 (0·11)
Age, depri&language adjusted	3·66 (0·07)	3·62 (0·08)	−0·05 (−0·26 to 0·17)	0·67	−0·05 (0·11)

Difference score is the low noise mean minus the high noise mean.

We have conducted MANOVA with an interaction term to test for gender interaction and we did not find any evidence to suggest that noise effects on reading ($P = 0{\cdot}38$) annoyance ($P = 0{\cdot}32$), noradrenaline ($P = 0{\cdot}35$); adrenaline ($P = 0{\cdot}09$) and cortisol ($P = 0{\cdot}48$) varied by gender.

of the airport contained predominantly ethnic minority populations, it was possible to match for level of social disadvantage. This careful matching is echoed in results because mother's education status, employment status, crowding and deprivation did not differ across high and low exposure areas (Table 1). There were more children from manual social class in the low noise schools (56·3%) compared with children in high noise schools (42·8%, $P = 0{\cdot}03$), although this may not be entirely accurate because of the rate of missing data for social class (38%).

Noise effects on cognitive performance

High and low noise exposed children did not differ in cognitive performance across all the functions measured: reading, immediate recall, delayed recall and recognition memory, sustained attention and serial backward digit recall (see Table 2).

Effect of noise on simple and difficult items of the Suffolk Reading Scale

We compared our reading results with those from the Munich Airport Study reading results. In Munich noise effects were only found on the most difficult items of the reading test. We carried out analyses to replicate this effect. It was hypothesized that chronic noise exposure will have a larger effect on difficult cognitive tests compared with simple tests. 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 priori test design and empirically on the performance on the whole sample of the most difficult items. 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 ($F(1{,}423) = 0{\cdot}172$, $P = 0{\cdot}679$, Fig. 1) when this was further adjusted for age, main language and deprivation the effect still remained insignificant ($F(1{,}417) = 0{\cdot}563$, $P = 0{\cdot}454$). 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 ($F(1{,}423) = 4{\cdot}75$, $P = 0{\cdot}03$, Fig. 2); when this was further adjusted

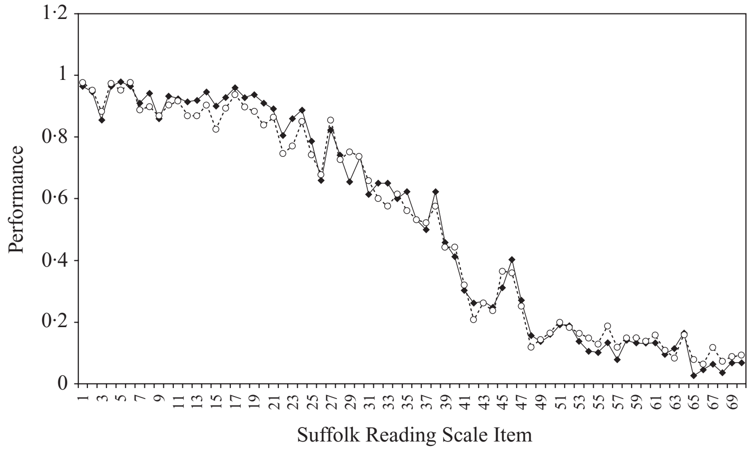

FIG. 1. Repeated measures general linear model examining the association between noise exposure on performance on the 70 items of the Suffolk Reading Scale (◆, high noise; ○, low noise).

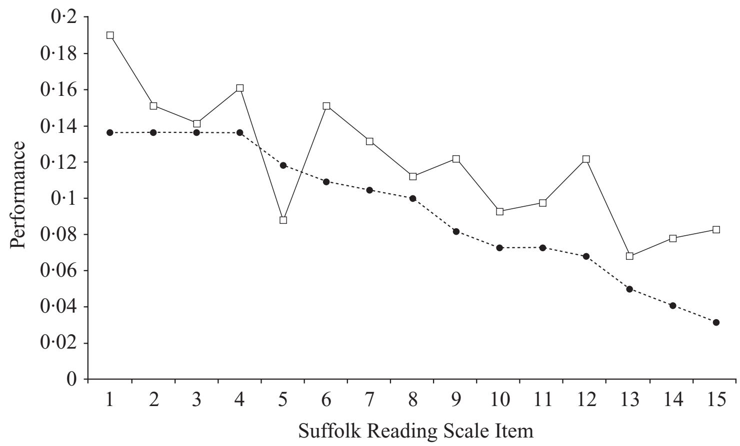

FIG. 2. Repeated measures general linear model examining the association between noise exposure on performance on the most difficult 15 items of the Suffolk Reading Scale (●, high noise: □, low noise).

for age, main language and deprivation the effect still remained significant ($F(1,417) = 4{\cdot}75$, $P = 0{\cdot}032$). Children in high noise schools had significantly poorer performance than children in the control schools on the difficult items. When this analysis was re-run using multi-level modelling, the same results were obtained and the difference was still significant.

Noise effects on annoyance, stress and health

Annoyance levels to aircraft noise were significantly higher among children in the high noise schools compared to the low noise schools (Table 3), after adjustment for age, main language spoken and deprivation. The high and low noise exposed children did not differ in overnight 12 hour secretion of noradrenaline, adrenaline and cortisol adjusted for creatinine, age, deprivation and language (see Table 3). Children exposed to high and low noise did not differ in perceived stress as rated on the Lewis Child Stress Scale (Table 3). 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 (Table 3). On the Strengths and Difficulties Questionnaire children in high noise schools had higher total scores

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Table 3. *Mean annoyance, stress and mental 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*

	High noise schools Mean (S.E.)	Low noise schools Mean (S.E.)	Difference score (95% CI)	*P*
Aircraft noise* annoyance at school				
Age adjusted	2·20 (0·098)	1·62 (0·10)	−0·586 (−0·86 to −0·31)	0·0001
Age, depri&language adjusted	2·20 (0·097)	1·65 (0·10)	−0·55 (−0·82 to −0·27)	0·0001
Perceived stress				
Age adjusted	3·57 (0·05)	3·67 (0·05)	0·11 (−0·03 to 0·24)	0·11
Age, depri&language adjusted	3·57 (0·05)	3·67 (0·05)	0·10 (−0·04 to 0·23)	0·15
Stress events frequency				
Age adjusted	2·03 (0·04)	2·14 (0·04)	0·11 (0·04 to 0·22)	0·04
Age, depri&language adjusted	2·03 (0·04)	2·14 (0·04)	0·11 (−0·01 to 0·22)	0·05
SDQ-conduct				
Age adjusted	1·99 (0·14)	1·81 (0·14)	−0·19 (−0·56 to 0·19)	0·33
Age, depri&language adjusted	1·20 (0·13)	1·80 (0·13)	−0·19 (−0·56 to 0·18)	0·30
SDQ-peer				
Age adjusted	2·15 (0·14)	2·01 (0·14)	−0·14 (−0·53 to 0·25)	0·48
Age, depri&language adjusted	2·13 (0·14)	2·03 (0·14)	−0·11 (−0·49 to 0·27)	0·58
SDQ-hyperactivity				
Age adjusted	4·81 (0·14)	4·14 (0·14)	−0·66 (−1·07 to −0·262)	0·001
Age, depri&language adjusted	4·80 (0·14)	4·15 (0·14)	−0·65 (−1·06 to −0·25)	0·001
SDQ-emotional				
Age adjusted	2·61 (0·16)	2·43 (0·16)	−0·18 (−0·63 to 0·27)	0·43
Age, depri&language adjusted	2·58 (0·16)	2·46 (0·16)	−0·13 (−0·57 to 0·32)	0·58
SDQ-total				
Age adjusted	11·56 (0·42)	10·39 (0·42)	−1·17 (−2·32 to −0·08)	0·04
Age, depri&language adjusted	11·51 (0·40)	10·43 (0·40)	−1·08 (−2·20 to 0·04)	0·06
Adrenaline/creatinine†				
Age adjusted	3·70 (0·40)	4·18 (0·38)	0·49 (−0·61 to 1·58)	0·38
Age, depri&language adjusted	3·70 (0·40)	4·18 (0·38)	0·48 (−0·62 to 1·59)	0·38
Noradrenaline/creatinine†				
Age adjusted	21·57 (1·13)	23·28 (1·07)	1·72 (−1·36 to 4·79)	0·27
Age, depri&language adjusted	21·52 (1·13)	23·33 (1·07)	1·80 (−1·28 to 4·90)	0·25
Cortisol/creatinine†				
Age adjusted	12·00 (0·67)	11·35 (0·64)	−0·65 (−2·49 to 1·19)	0·48
Age, depri&language adjusted	11·98 (0·68)	11·36 (0·65)	−0·62 (−2·48 to 1·23)	0·51

* Multi-level models for aircraft noise annoyance at school difference score and standard error: age adjusted −0·601(0·262), age, deprivation and language adjusted −0·58(0·26).

† Adrenaline, noradrenaline and cortisol are reported in nmol/μmol

The difference score is the low noise mean minus the high noise mean.

than children in low noise schools, which was marginally significant after adjustment for age, main language spoken and deprivation (Table 3). The high noise children also had higher rates of hyperactivity than the low noise children after adjusting for age, main language spoken and deprivation (Table 3).

Noise effects in subgroups of children

The results of the stratified analyses indicate that for reading and 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, children in deprived and not deprived households (for complete results see Stansfeld *et al*. 2000*a*).

Noise exposure levels

The majority of children in high noise schools heard aircraft noise at school (95%) and at home (94%). High noise school children heard significantly more aircraft noise than low noise school children. Seventy-four per cent of high noise sample lived in high aircraft noise exposed homes (> 63 dBA Leq 16 h). Ninety-six per cent of the low noise sample lived in low aircraft noise homes (< 57 dBA Leq 16 h). There was a distinct difference between high and low chronic aircraft noise exposed schools in terms of acute aircraft noise exposure during testing (for acoustical results see Stansfeld *et al.* 2000*a*).

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 subgroups of children. The results of this study partially confirm the results from previous studies as noise exposure was associated with impaired reading and raised annoyance. There was no variation in the size of the noise effects in vulnerable subgroups 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 with overall reading scores, in memory and attention or raised catecholamine secretion and self-reported stress. Aircraft noise exposure was weakly associated with hyperactivity and psychological morbidity.

The effects of noise on child cognitive performance

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 standardized 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). Analysis of school level factors using multi-level modelling and multivariate adjustment for individual level deprivation and main language spoken had very little impact on the association between aircraft noise exposure, cognitive performance and health, suggesting that differences between primary schools and individual social factors did not explain noise 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*b*). 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 from field and laboratory studies are consistent with this explanation (Cohen *et al.* 1986; Smith & Broadbent, 1992; Smith & Jones, 1992; Evans & Lepore, 1993; Hygge, 1994; Evans *et al.* 1995, 1998; Enmarker *et al.* 1998; Meis *et al.* 1998).

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 for social disadvantage. Other researchers have found that noise effects are more marked in low school achievers (Kryter, 1985), future research should identify vulnerable subgroups of children.

Memory and attention

Our cognitive data reveal a mixed pattern of results. We found no association between noise exposure and our cognitive control outcomes recognition and working memory measured by the backwards digit recall task which replicates the Munich Study (Evans *et al.* 1995) and our previous study around Heathrow (Haines *et al.* 2001*a*). However, we did not find an effect on long-term memory recall and sustained attention thereby not confirming our hypothesis. Given the strength of the previous studies particularly the Munich Airport study with its within-subjects prospective natural experimental design these negative results do not undermine previous findings on memory, however, given the strength of our test they do suggest that further studies are needed. Previous experimental studies and field studies have yielded equivocal attention results. In contrast to the methodologically weak studies where positive attention results have been found (Karsdorff & Klappach, 1968; Kyzar, 1977; Heft, 1979; Moch-Sibony, 1984; Hambrick-Dixon, 1986; Sanz *et al*. 1993; Muller *et al*. 1998), Evans and colleagues (1995) did not find that chronic noise exposure was associated with poorer attention performance on an embedded figures task. 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.

Noise annoyance

Consistent with previous studies of children and adults, aircraft noise exposure was associated with raised annoyance after adjustment for age, main language spoken and social deprivation at the individual and school level. The stratified analyses indicate that there was no variation in the size of the noise annoyance effect within subgroups. It is not clear whether high levels of aircraft noise annoyance in children have long-term health implications for children, 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 standardized child annoyance scale.

Mental health

Unexpectedly, aircraft noise was weakly associated with hyperactivity and psychological morbidity measured by the Strengths and Difficulties Questionnaire (SDQ) after adjustment for age, main language spoken and social deprivation at the individual and school level. These mental health results are not consistent with our previous study around Heathrow airport (Haines *et al*. 2001*a*). The results in this study from the SDQ indicate that noise exposure may influence externalized psychological disorders such as hyperactivity that are behaviourally manifest rather than internalized and emotional disorders (e.g. depression and anxiety). 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 lead on to raised activity level that might become manifest as chronic hyperactivity. The children in the low noise exposed schools reported having exerienced 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 found in previous studies (Evans *et al*. 1995; Haines *et al*. 2001*b*). Given that aircraft noise was only weakly associated with psychological morbidity and not associated with perceived stress which it is not consistent with previous studies, these effects needs to be replicated before a definite conclusion can be drawn.

Catecholamines

Contrary to expectation, there was not an association between noise exposure and adrenaline and noradrenaline 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 alone. The lack of an association between cortisol levels and noise exposure were consistent with some of the previous research (Evans *et al*. 1995, 1998; Haines *et al*. 2001*a*). Whether noise has any effects on catecholamine secretion is still an open question due to the contradiction in results between these results and those of the Munich airport study (Evans *et al*. 1995, 1998).

Strengths and limitations

In the West London Schools Study attempts, were made to improve on the previous study around Heathrow Airport (Haines *et al*. 2001*a*, *b*) and other cross-sectional field studies (Cohen *et al*. 1980; Evans & Maxwell, 1997) to reduce possible biases related to differences between schools and individual levels of social deprivation. This was achieved by choosing larger numbers of schools, and by successfully matching for socio-economic position between high and low noise exposed schools. 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 further evidence concerning the nature of cognitive noise effects. The results indicate that chronic aircraft noise exposure does not always lead to generalized cognitive effects but more selective cognitive impairments in children exposed to chronically high levels of noise exposure (Wachs & Gruen, 1982; Cohen *et al*. 1986; Evans & Cohen, 1987; Evans *et al*. 1995). The noise effect on reading confirms previous studies (Evans & Lepore, 1993; Evans *et al*. 1995, Evans & Maxwell, 1997; Haines *et al*. 2001 *a*, *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.

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