Psychological Medicine, 2001, **31**, 265–277. Printed in the United Kingdom

Chronic aircraft noise exposure, stress responses, mental health and cognitive performance in school children

M. M. HAINES,[1] S. A. STANSFELD, R. F. S. JOB, B. BERGLUND AND J. HEAD

From the Department of Psychiatry, St Bartholomew's and The Royal London School of Medicine and Dentistry, Queen Mary and Westfield College and Department of Epidemiology and Public Health, University College London and the Royal Free Medical School, London; Department of Psychology, University of Sydney, NSW, Australia; and Institute of Environmental Medicine, Karolinska Institute and Department of Psychology, University of Stockholm, Sweden

ABSTRACT

Background. Previous research suggests that children are a high risk group vulnerable to the effects of chronic noise exposure. However, questions remain about the nature of the noise effects and the underlying causal mechanisms. This study addresses the effects of aircraft noise exposure on children around London Heathrow airport, in terms of stress responses, mental health and cognitive performance. The research also focuses on the underlying causal mechanisms contributing to the cognitive effects and potential confounding factors.

Methods. The cognitive performance and health of 340 children aged 8–11 years attending four schools in high aircraft noise areas (16 h outdoor Leq >66 dBA) was compared with children attending four matched control schools exposed to lower levels of aircraft noise (16 h outdoor Leq < 57 dBA). Mental health and cognitive tests were group administered to the children in the schools. Salivary cortisol was measured in a subsample of children.

Results. Chronic aircraft noise exposure was associated with higher levels of noise annoyance and poorer reading comprehension measured by standardized scales with adjustments for age, deprivation and main language spoken. Chronic aircraft noise was not associated with mental health problems and raised cortisol secretion. The association between aircraft noise exposure and reading comprehension could not be accounted for by the mediating role of annoyance, confounding by social class, deprivation, main language or acute noise exposure.

Conclusions. These results suggest that chronic aircraft noise exposure is associated with impaired reading comprehension and high levels of noise annoyance but not mental health problems in children.

INTRODUCTION

Environmental pollutants such as noise may impair early childhood development and education and have life-long effects on achievement of academic potential and good health (Evans *et al*. 1991). Child health, defined broadly, may be adversely affected by a number of environmental stressors (crowding – Rodin, 1977; Saegert, 1981; Evans *et al*. 1991, air pollution – Evans *et al*. 1991; Bobak & Leon, 1992, rundown housing and slums (Agenda 21 United Nations and noise) – Cohen *et al*. 1980; Evans *et al*. 1995). Furthermore, children may be more susceptible to environmental stressors than adults because of less cognitive capacity to understand en-

[1] Address for correspondence: Dr Mary M. Haines, Department of Psychiatry, St Bartholomew's and The Royal London School of Medicine and Dentistry, Queen Mary and Westfield College, Basic Medical Sciences Building, Mile End Road, London E1 4NS.

https://doi.org/10.1017/S0033291701003282 Published online by Cambridge University Press

vironmental issues, anticipate stressors and lack of well-developed coping repertoires (Cohen *et al*. 1986; Evans *et al*. 1991).

The most consistent effects of aircraft noise exposure found in children are cognitive impairments (Cohen *et al*. 1986; Evans *et al*. 1991; Evans & Lepore, 1993). Tasks that involve central processing and language comprehension, such as reading, attention, problem-solving and memory appear to be most affected by exposure to noise (Cohen *et al*. 1986; Evans & Lepore, 1993; Hygge, 1994; Evans *et al*. 1995). These cognitive effects, initially found in the laboratory, have been confirmed in longitudinal field studies around Los Angeles Airport (cross-sectional results Cohen *et al*. 1980, follow-up results Cohen *et al*. 1981) and Munich Airport (cross-sectional results Evans *et al*. 1995, longitudinal results Hygge *et al*. 1996; Evans *et al*. 1998) showing that chronic aircraft noise exposure is consistently associated with cognitive impairments in school children. In 1992 the old Munich airport closed and a new airport was opened. The cross-sectional results indicate an association between high noise exposure and poor long-term memory, reading and motivation (Evans *et al*. 1995). Longitudinal analyses, after three waves of testing, indicate improvements in long-term memory after closure of the old airport. Strikingly, these effects were paralleled by impairment of the same cognitive skills in the newly noise exposed group after the new airport opened (Hygge *et al*. 1996).

Despite the converging evidence for cognitive main effects, the underlying causal mechanisms of these effects have been relatively neglected. An exception is the research of Evans & Maxwell (1997), that suggests that speech perception partially mediates the detrimental effects of noise on reading. Alternative accounts of these cognitive and motivational effects are possible and other mediating factors remain to be elucidated. Noise exposure has been linked to annoyance and diminished quality of life in children (Bronzaft & McCarthy, 1975; Cohen *et al*. 1980; Evans *et al*. 1995). This can be interpreted as a chronic affective response of impaired well-being, which in turn, could lead to chronic distraction. It is plausible that this perceived disturbance could interfere with school performance leading to poorer cognitive performance. The present research will directly test the mediating role of noise annoyance in noise-induced cognitive impairments.

The issue of whether environmental noise, particularly aircraft noise, affects mental health has been extensively researched in adults but not in children (Tarnopolsky & Morton-Williams, 1980; Stansfeld *et al*. 1993). Many previous studies have shown the noise exposure causes noise annoyance, but there is little evidence for a causal role in mental illness in adults. The question of whether chronic aircraft noise exposure is a contributing factor responsible for mental health problems in children was tested in the present research by measuring a range of indices of psychological distress.

The Munich Airport Study was the first field study to examine neuroendocrine indices of chronic stress among persons exposed community noise (Evans *et al*. 1995). Overnight resting levels of urinary catecholamines were significantly higher in children chronically exposed to aircraft noise than those unexposed around the old airport (Evans *et al*. 1995) and around the new airport (Evans *et al*. 1998). Measurement of biological stress markers, such as catecholamines and cortisol, also serves to complement of self-reported stress responses (Kirschbaum & Hellhammer, 1994). As chronic effects of aircraft noise were anticipated, salivary cortisol was measured in this present research on a subsample.

We compared the cognitive performance and health of children aged 8–11 years attending four schools in high aircraft noise areas with those of children attending four matched control schools exposed to lower levels of aircraft noise. It was hypothesized that children exposed to high levels of aircraft noise would have raised stress responses and poorer cognitive performance than the children attending the control schools, after adjustment for social deprivation and main language spoken at home. No noise effects were hypothesized for depression and anxiety. Noise annoyance was tested as a mediating factor in the association between noise exposure and cognitive performance. The potential moderating role of acute noise exposure on the relationship between chronic school noise exposure and child health and performance was also examined.

METHOD

Participants

Eight co-education state primary schools were chosen according to the noise exposure of the school area. The participants were 340 fourth ($N = 163$) and fifth ($N = 177$) grade pupils (mean age, 9 years and 8 months, range from 8 years 7 months–10 years 10 months, 50% girls, 50% boys); 169 attended school in a high-aircraft noise-impact urban area (16 h outdoor Leq > 66 dBA) and 171 attended school in a low-aircraft noise-impact urban area (16 h outdoor Leq < 57 dBA) surrounding Heathrow Airport in West London (Leq is a measure of long-term average noise level expressed in dB(A). It is the level of steady sound which, if heard continuously over the same period of time, would contain the same total sound energy as the actual varying sound).

The participants also included 21 teachers and 284 parents. The high noise exposed schools were selected first and then matched with the control schools, according to the following criteria, in this order of priority: (*a*) age of the children; (*b*) sound level at the school from non-aircraft sources; (*c*) the extent of existing noise protection in the schools; (*d*) socio-economic group distribution and unemployment rate; and (*e*) proportion of ethnic groups in area based on electoral ward analysis. These matching data were collected from the schools (age, the extent of existing noise protection in the schools), school site inspection (sound level at the school from non-aircraft sources), ward analysis from 1991 Census (socio-economic group distribution, unemployment rate and ethnicity). Matching was efficiently achieved for age, other noise sources apart from aircraft noise and existing noise protection in schools. It was more difficult to match for socio-economic groups and proportion of ethnic groups given the availability of eligible schools.

Stress response and health outcome measures

Annoyance

Noise annoyance was measured with seven child adapted standard questions (Fields *et al.* 1997). These questions assessed the level of annoyance (very much, quite a bit, a little, not at all) felt by the child when they heard four sources of environmental noise without a timeframe. The sources of environmental noise were: aircraft noise, train noise, road traffic and neighbours' noise (only at home).

Cortisol

Salivary cortisol was measured in the morning prior to cognitive performance testing and 1 h later at the end of testing. We screened for potential contamination and activities that may raise cortisol including: touching the cotton wool with fingers, high protein meal 1 h before testing, eating 30 min before cortisol measurement, medication, a stressful life event in the last 2 days, smoking, physical activity and mouth infection/bleeding gums. Saliva specimens were collected in Salivettes (Sarstedt, Leicester, UK). Cortisol in saliva was quantified by means of the 'Magic Cortisol' radioimmunoassay (RIA) kit (Ciba-Cornig, Halstead, Essex, England) based on an established method (Kirschbaum *et al.* 1989) but slightly modified in the following way: (*a*) the lowest and highest standards were 0·7 and 96·6 nmol/l respectively; (*b*) the incubation time was shortened to 30 min at 37 °C and the precipitate was washed once with phosphate buffered saline (0·3 ml) containing 1% (v/v) Tween 20. Two outcomes are reported: (1) 'baseline cortisol'; (2) 'time 2 cortisol' taken after the cognitive testing.

Depression

This was measured with the short version of the Child Depression Inventory (CDI; Kovacs & Beck, 1977, modified for an English sample, Charman, 1994). The CDI is the most widely used instrument to measure depression in children from 8–16 years old (Kazdin, 1981). The CDI is a 14-item forced choice self-report inventory with high internal consistency and stability (Charman, 1994).

Anxiety

Anxiety was measured with the Revised Child Manifest Anxiety Scale (CMAS; Reynolds & Richmond, 1978). The CMAS is a 28-item forced choice self-report inventory of chronic anxiety reactions.

Strengths and Difficulties Questionnaire (SDQ)

A questionnaire was sent home with the child for a carer to complete. This questionnaire measured child physical and mental health and sociodemographic variables. The measure of psychological morbidity included in this questionnaire was the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1994) which is designed to detect behavioural, emotional or relationship difficulties 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 pro-social behaviour. The total deviance 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).

Self-reported child health

This was measured by using standard self-report questions derived from the General Household Survey about general symptoms such as headaches, tiredness, and trouble sleeping (OPCS, 1989).

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 socioeconomically mixed national sample of primary-aged school children. The scale has good construct validity, test–retest reliability and internal consistency (Hagley, 1987).

Long-term memory

The task was modelled on that used by Evans *et al.* (1995) to measure the recognition and recall of reading material 1 week after reading a passage. A reading passage was administered to each child 1 week before the long-term memory recall task. The long-term memory recall task involved six multi-choice questions (the recognition task) and three written recall items (the recall task). Two scores were calculated: (1) recognition task score was the number of correct items in the multi-choice task; (2) recall task score was calculated by coding the written recall items using a method similar to that of Evans *et al.* (1995).

Short-term memory

This was measured by six trials of a serial digit recall task (two five-digit trials, two seven-digit trials and two nine-digit trials). The answers were scored for correct serial recall. The total short-term memory score was calculated by summing the average score across the two trials of the same length.

Motivation – performance measure

Two puzzles adapted from Glass & Singer's after-effects paradigm of soluble and insoluble animal puzzles (Glass & Singer, 1972) used in the Munich airport research were employed to measure motivation (Evans *et al.* 1995). The initial puzzle was insoluble and the index of motivation was: (1) the number of attempts to solve this puzzle; and (2) the time taken persisting with it. The second puzzle was soluble. The order of the puzzles was deliberately fixed so that each child would experience success following initial failure on the first puzzle. The task was timed out at 10 min. The children were placed in small groups of 3–6 with a different researcher to record completion time in minutes and seconds and to answer questions.

Child attributional style

Attributional style was measured with the revised 24-item Child Attribution Style Questionnaire (CASQ; Kaslow & Nolen-Hoeksema, 1991).

Classroom motivation teacher questionnaire

Teachers were asked to rate on the 24-item Student Behaviour Checklist (SBC; Fincham *et al.* 1989) the extent to which a child engages in learned helplessness (e.g. 'when s/he begins a difficult problem, his/her attempts are half hearted') or mastery orientated behaviour (e.g. 'expresses enthusiasm about his/her work') in the classroom. The SBC has good construct validity (Nolen-Hoeksema *et al.* 1986; Fincham *et al.* 1989) and high internal consistency

(Fincham *et al*. 1989). Higher scores indicate greater learned helplessness.

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, crowding, home ownership and unemployment in a single scale (these data were collected from parents). 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) and because there was 40% (40% high noise, 40% low noise), missing data for social class as opposed to 19% (15% high noise, 21% low noise) missing for deprivation. 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 3 days each a week apart, counterbalanced for questionnaire order and time of day across noise exposure in the classrooms. The teachers and parents were given their questionnaires in the same month as the testing sessions. Ethical procedures when conducting research on school children were strictly adhered to, including gaining ethical approval and parental and child consent prior to testing. The study was introduced as a Health and Environment study in parents and children to the teachers, parents and children. This introduction did not focus on noise to avoid response bias. Noise questions were embedded in the health and environment section to counter the possibility of 'halo effects' biasing responding.

Chronic noise measurements procedure

Schools were chosen within the published 1991 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 from 15 June to 15 September in 1991. After the school selection the 1994 Civil Aviation Authority Contours were published. Two of the high noise (HN) exposed schools that were situated within the 63 dBA Leq contour were relocated within the 66 dBA Leq contour, making all four schools located with the 66 dBA Leq contour. Low aircraft noise (LN) schools remained outside the 57 dBA Leq contour.

Acute noise measurement procedure

Measurements at individual schools were carried out to assess indoor sound levels of aircraft noise during testing. These measurements were taken in the classrooms at the time of testing using a sound level meter mounted on a tripod and a portable DAT recorder. Two measurements are reported: (1) SEL dBA to describe the acute levels of noise interference at the time of testing (single event noise exposure level (SEL) is defined as the total sound energy of an event expressed as a one second equivalent: SEL is a measure of sound energy that allows for the direct comparison of sound events of differing duration); (2) LAeq(T) which is the sound level of a steady sound having the same sound energy as a fluctuating or intermittent sound over a specified measurement period (T) taken for task completion. This measure is used in analyses examining the effect of acute noise on performance.

Other measures of noise exposure

Data on aircraft noise exposure levels at each participating child's home were also taken from the 1991 CAA contour maps. Self-reported home and school noise exposure were assessed from four sources of environmental noise (trains, road traffic, planes, neighbour noise). School records indicated the length of time that the child had attended the school.

Statistical procedures

Three factors were adjusted for in the noise effects analyses in the ANCOVA models namely: age (at the time of testing); main language spoken at home (English and non-English); and, household deprivation (deprived and non-deprived). All statistical tests are two-tailed and the alpha value was set at 0·05. The results tables contain mean scores and *P* values. Confidence intervals and *F* tests will be presented for the significant main effects.

Procedural error

A procedural error occurred in the testing session, over which the researchers had no control. The final low noise control school (26 students included in the analyses) supplied classes of lower ability rather than the requested representative children. Seventy-one per cent of the sample from this school came from deprived homes, which was much higher than the sample average level of deprivation (43·5%). This school's performance in reading comprehension was also significantly different from the other low noise schools confirming that it was an outlier ($F(3, 122) = 9{\cdot}46$, $P = 0{\cdot}0001$). This school was not included with three low noise schools in a combined analysis. Therefore, the results will be presented on all eight schools and the seven schools excluding the school with the biased sample selection.

RESULTS

The samples and response rate

The response rate was 77% for children, 84% for parents and 100% for teachers across the eight schools. The response rate did not differ between high and low noise exposed parents (86% high noise, 81% low noise, $P = 0{\cdot}258$) and children (78% high noise, 76% low noise, $P = 0{\cdot}86$). The sample was well matched across noise levels for: class at school and sex (Table 1). The high noise school sample had a much higher proportion of non-white pupils and pupils with languages other than English as the main language spoken at home than the low noise schools (Table 1). The high noise school sample had a higher proportion of pupils from manual social class households indicated by the registrar general's classification and participants from deprived households than the low noise schools (Table 1). The samples also differed in proportion of household within each socio-economic group (Table 1).

Noise effects on stress and health

Annoyance

Chronic exposure to high levels of aircraft noise was associated with higher levels of annoyance in the analyses of the eight schools (HN mean = 12·1 (CI 11·45–12·72) LN mean = 10·5 (CI 9·88–11·16), $F(1, 251) = 11{\cdot}04$, $P = 0{\cdot}001$) and the seven schools (HN mean = 12·1 (CI 11·45–12·72) LN mean = 10·5 (CI 9·74–11·19), $F(1, 229) = 9{\cdot}65$, $P = 0{\cdot}002$) (see Table 2). Chronic exposure to high levels of aircraft noise was not related to annoyance to other sources of environmental noise from trains, road traffic or neighbours. When annoyance was further ad-

Table 1. *The sociodemographic characteristics of the high and low noise child samples: frequencies and proportions, continuity correction chi-square P value*

Socio-demographic characteristic Total	High noise ($N = 169$) N (%)	Low noise ($N = 171$) N (%)	Chi-square P value
Year 4	82 (49)	81 (47)	
Year 5	87 (51)	90 (53)	0·92
Girls	86 (51)	85 (50)	
Boys	83 (49)	86 (50)	0·99
White	58 (37)	147 (88)	
Non-white	98 (63)	20 (12)	0·0001
English – main language spoken at home	101 (65)	154 (93)	
Non-English	55 (35)	12 (7)	0·0001
Non-manual social class (1,2,3N)	47 (47)	62 (60)	
Manual social class (3M,4,5)	54 (53)	41 (40)	0·059
Professional groups SEGs (1,2,3,4)	21 (20)	32 (30)	
Other non-manual workers SEGs (5,6)	27 (26)	33 (31)	
Skilled manual workers SEGs (8,9,12)	28 (27)	29 (28)	
Semi-skilled manual worker SEGs (7 & 10)	14 (14)	9 (9)	0·005*
Unskilled SEG (11)	12 (12)	1 (1)	
Others SEGs (13,14,15,16,17)	1 (1)	1 (1)	
Not deprived	76 (53)	87 (64)	
Deprived	68 (47)	49 (36)	0·076

Total percentages reported are of those known. Missing data are generally a small proportion of the sample, except in the case of social class, socio-economic group and deprivation.
* Chi-square for likelihood ratio for five groups not including other SEGs.

Table 2. *Stress responses and mental health outcome mean scores adjusted for age, deprivation and main language spoken in the four high-noise (HN) schools, the four low-noise (LN) schools and the three LN schools (excluding the procedural error school)*

Stress and health outcome	Schools HN (4)	LN (4)	LN (3)	*P**	*P*†
Annoyance	12·09	10·52‡	10·46‡	0·001	0·002
Baseline cortisol	7·5 nm/l	n/a	8·13 nm/l	n/a	0·282
Time 2 cortisol level	7·7 nm/l	n/a	6·7 nm/l	n/a	0·556
After cognitive testing					
Depression (CDI)	5·24	4·56	4·53	0·17	0·179
Anxiety (CMAS)	12·6	11·9	11·96	0·399	0·328
Prosocial behaviour score	8·22	8·11	8·02	0·65	0·314
Hyperactivity score	3·44	3·49	3·38	0·871	0·764
Emotional symptoms	1·95	2·13	2·02	0·491	0·971
Conduct problems score	1·5	1·42	1·27	0·769	0·246
Peer problems score	1·89	1·82	1·68	0·73	0·238
SDQ Total	8·77	8·86	8·33	0·902	0·45

* Eight schools comparison.
† Seven schools comparison.
‡ $P<0·05$.
When annoyance was further adjusted for ethnicity as well as deprivation, age and main language spoken at home the noise effect remained in the eight schools (HN mean = 12·2, LN mean = 10·4, $F(1, 250) = 13·36$, $P = 0·001$) and seven schools (HN mean = 12·3, LN mean = 10·4, $F(1, 236) = 11·42$, $P = 0·001$).
Cortisol was only taken on a subsample of the total sample and the procedural school was not included in the subsample. The cortisol analyses were adjusted for age and time of sample collection and not main language and deprivation.

Table 3. *Cognition and performance outcome mean scores adjusted for age, deprivation and main language spoken in the four high-noise (HN) schools, the four low-noise (LN) schools and the three LN schools (excluding the procedural error school)*

Cognition and performance outcome	Schools HN (4)	LN (4)	LN (3)	*P**	*P*†
Reading comprehension	98·48	100·01	102·66‡	0·334	0·009
Long-term memory recall task	2·56	2·47	2·66	0·735	0·665
Long-term memory recognition task	3·84	4·12	4·26‡	0·221	0·05
Short-term memory	8·53	8·77	8·75	0·56	0·73
Motivation (no. of attempts to solve insoluble puzzle)	5·86	5·91	5·93	0·943	0·912
Child Attributional Style (CASQ – composite score)	4·07	3·73	3·51	0·423	0·183
Classroom Motivation (Total Score SBC)	−15	−15·68	−16·86	0·831	0·38

* Eight school comparison (*F* statistic).
† Seven school comparison (*F* statistic).
‡ $P < 0·05$.
The effect of noise on reading comprehension was larger for girls than boys in the eight schools ($F(1, 241) = 4·55$, $P = 0·034$) (Stansfeld & Haines 1997).
When reading comprehension was further adjusted for ethnicity as well as deprivation, age and main language spoken at home the noise effect remained (HN mean = 98·1, LN mean = 103·0, $F(1, 219) = 6·82$, $P = 0·01$).
The lower the total score on the CASQ and the SBC the more depressive the attributional style.

justed for social class as well as deprivation, age and main language spoken at home the noise effect remained in the eight schools (HN mean = 12·1, LN mean = 10·6, $F(1, 251) = 10·54$, $P = 0·001$) and seven schools (HN mean = 12·1, LN mean = 10·6, $F(1, 237) = 8·14$, $P = 0·005$).

Cortisol

The two groups did not significantly differ in baseline cortisol level or time two cortisol level adjusting for age and time of sample collection (Table 2). We also tested for an interaction between school noise level and change in cortisol level from baseline to post-testing and did not find an effect ($F(1, 236) = 0{\cdot}01$, $P = 0{\cdot}938$). The potentially confounding factors measured did not have independent effects on cortisol level.

Anxiety and depression

The two groups did not significantly differ in mean scores of anxiety and depression (Table 2), neither was aircraft noise exposure related to higher prevalence of depressive and anxiety symptoms as measured by scores above the clinically relevant cut-off points of the CDI and CMAS, respectively.

Psychological disturbance

Aircraft noise exposure at school was not significantly associated with scores on the SDQ completed by parents (Table 2).

Child and parent reported physical health

Aircraft noise exposure at school had no significant effect on child self-reported general health, headaches, tiredness and sleeping troubles.

Noise effects on cognition and performance

Reading comprehension

Chronic exposure to aircraft noise had no significant effect on reading comprehension in the analyses of the eight schools (Table 3). However, in the seven schools, children in the four high noise exposed schools had poorer reading comprehension than children in the three low noise schools (HN mean = 98·5 (CI 96·20–100·41) LN mean = 102·7 (CI 103·55–104·92), $F(1, 220) = 6{\cdot}93$, $P = 0{\cdot}009$, Table 3). This difference in mean performance is equivalent to 6 months delay in reading ability. When reading comprehension was further adjusted for social class as well as deprivation, age and main language spoken at home the noise effect remained (HN mean = 98·4, LN mean = 101·9, $F(1, 220) = 4{\cdot}5$, $P = 0{\cdot}035$).

Memory

Chronic exposure to aircraft noise had no significant effect on recall performance and short-term memory and recognition (in the analyses of the eight schools) (Table 3). However, in the seven schools, children in the four HN exposed schools had poorer long-term memory recognition than children in the three LN schools ($F(1, 215) = 3{\cdot}84$, $P = 0{\cdot}05$, Table 3).

Motivation

The HN and LN exposed groups did not differ in level of motivation measured by the Glass and Singer performance measures of motivation (Table 3).

Attributional style and learned helpless classroom motivation

The HN and LN exposed groups did not differ in child self-reported attributional style and teacher ratings motivation (Table 3).

Relationships between psychological, environmental and performance effects

Annoyance as a mediating factor

Noise annoyance score was entered as a covariate in an ANCOVA model (with the Independent Variable – school noise level: high or low and the Dependent Variable – reading comprehension score; covariates: age, main language spoken at home, household deprivation). The significance level of the main reading effect in the seven schools was not altered by the adjustment for noise annoyance ($F(1, 208) = 5{\cdot}57$, $P = 0{\cdot}01$), even though higher noise annoyance was associated with poorer reading ($B = -0{\cdot}39$, $P = 0{\cdot}05$).

Environmental moderating factors

The moderating effect of acute aircraft noise could not be examined because acute noise and chronic school noise were highly correlated. Sound levels at the time of testing were regressed against reading comprehension and annoyance within the high noise sample. Mean LAeq was calculated for aircraft noise interference for the specific duration of the each of the tasks, in each of the high noise schools respectively (range of the mean dBA Leq was 0–55). Level of acute aircraft noise exposure at the time of testing was not associated with reading comprehension ($B(1, 131) = 0{\cdot}16$, $P = 0{\cdot}5$) or annoyance ($B(1, 157) = -0{\cdot}02$, $P = 0{\cdot}78$).

Noise exposure levels

Home noise exposure

Eighty per cent of the HN sample lived in high aircraft noise exposed homes (> 63 dBA Leq

https://doi.org/10.1017/S0033291701003282 Published online by Cambridge University Press

16 h) and 86% of the LN sample lived in low aircraft noise homes (< 57 dBA Leq 16 h). 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.

Acute noise exposure

Appendix 1 contains the acute levels of aircraft noise at the time of testing in single event noise exposure levels (SEL dBA). There was a distinct difference between high and low chronic aircraft noise exposed schools in terms of acute aircraft noise exposure during testing.

Length of time at the school

Ninety-two per cent of the HN sample had been attending the HN schools for more than 4 years, 88% of the LN sample of the children had been attending the LN schools for more than 4 years. Thus, the description of the relevant noise exposures as chronic is justified.

Perception of noise exposure

Aircraft noise exposure at school was strongly associated with perception of plane noise at school: 92% of the children in HN schools agreed that they could hear plane noise at school, compared with 61% of the children in LN schools ($\chi^2(1, 311) = 41{\cdot}63$, $P = 0{\cdot}0001$).

DISCUSSION

There were four main findings. First, chronic aircraft noise exposure was consistently and strongly associated with higher levels of noise annoyance in children. Secondly, the association between chronic aircraft noise exposure and reading comprehension and long-term memory recognition, is suggestive that chronic aircraft noise exposure impairs cognitive function. Thirdly, the association between aircraft noise exposure and reading comprehension could not be accounted for by noise annoyance, acute noise interference and sociodemographic factors (age, main language spoken at home, household deprivation, social class). Fourthly, chronic exposure to aircraft noise was not associated with child mental health problems (anxiety, depression, hyperactivity and conduct problems). The results provide evidence that there are grounds for concern regarding the effect of chronic aircraft noise on child stress responses and cognition and that further research is required to examine the causes and long-term implications of these effects.

The most consistent finding in this study is that children exposed to high levels of aircraft noise at school have higher levels of noise annoyance than children in low noise exposed schools. This effect remained after adjustments for age, deprivation and main language spoken. This annoyance effect is consistent and specific because children in high noise schools were also more aware of aircraft noise at school and at home than the low noise sample. The fact that aircraft noise exposure was only related to aircraft noise exposure and not road or rail exposure, suggests that aircraft noise annoyance is an effect specific to aircraft noise exposure.

It might be argued, however, that annoyance responses are merely transmitted to children by their parents. However, the evidence does not support this contention because parent annoyance level (usually mothers' annoyance level) and child annoyance levels were not related in this study ($r = 0{\cdot}1$, $P = 0{\cdot}07$ Stansfeld & Haines, 1997). Therefore, it is unlikely that these child results can be attributed to parental influence over children's responses. In many ways child noise annoyance may be less subject to bias because children are less affected by other factors that influence annoyance in adult samples, namely: political and environmental attitudes (Berglund & Lindvall, 1995; Fields, 1992; Job, 1988, 1996).

It is plausible that noise annoyance responses should be associated with behavioural manifestations of emotional disturbance. However, there was little evidence from the results of the SDQ that annoyance had behavioural consequences, such as, undisciplined behaviour, because there was no difference between the two groups in conduct problems and pro-social behaviour. Annoyance was weakly correlated with anxiety and depression indicating that is a related response but distinct from mental ill-health. 'Annoyance' is generally defined as a mixture of anger, fear and mild irritation (Cohen & Weinstein, 1981; Averill, 1982).

It is important to recognize that even young children report disturbance by environmental noise because the long-term health consequences of persistent annoyance are unknown (Stansfeld, 1992). Studies in adults have found that community noise annoyance does not habituate over time if the noise source persists (Weinstein, 1982). It is likely this will be the same in children. The public health consequences for children maturing in a neighbourhood that is perceived as annoying are unknown and could potentially be damaging for communities exposed to high levels of environmental noise.

Raised cortisol, measured in saliva, is an indicator of severe chronic stress reaction. In this study cortisol levels in children did not differ by chronic noise exposure. This suggests that either aircraft noise exposure was not sufficiently stressful to raise cortisol levels or that children's hormonal systems have adapted to such chronic stress exposure or that chronic stress exposure blunts cortisol responsivity or that the adopted measures were not sensitive enough. Little research has been carried out on cortisol in children but the Munich study (Evans *et al.* 1995) also found no association between noise and cortisol level (urine samples). It is possible that cortisol level, measured in the morning, at a time of maximum fluctuation may show too much circadian variation for a small noise effect to be detected. Cortisol is extremely sensitive to diurnal variation in rhythms which could also account for the negative result. A more direct measure of child self-reported stress responses may clarify the annoyance response and be a more sensitive measure of child stress responses to supplement the cortisol measures.

Chronic exposure to aircraft noise was not associated with child mental health problems (anxiety, depression, hyperactivity, conduct and peer problems). The high noise exposed group of children were exposed to very high levels of aircraft noise and the analyses were well-controlled sociodemographically, yet differences in mental health across a range of standard indices were neglible. This negative finding is in support of the adult mental health epidemiological studies (Tarnopolsky & Morton Williams, 1980; Stansfeld *et al.* 1996) and child noise studies (Poustka *et al.* 1992; Evans *et al.* 1995).

We found that noise annoyance did not mediate the link between noise exposure and reading comprehension. This has not been tested previously. However, it is also possible that annoyance may potentiate the relationship between noise exposure and cognitive effects. Unfortunately, there is no data to assess the reliability of the annoyance questionnaire, which means that it is possible the imprecision of the annoyance scale may have influenced the mediational analyses.

The main theory guiding research into noise related cognitive impairments has been that noise restricts attention to central cues during complex language related tasks (Cohen *et al.* 1980, 1986; Heft, 1985; Evans & Lepore, 1993). Children may adapt to noise interference during activities by filtering out sound stimuli, including relevant auditory stimuli as well as the unwanted noise. This tuning out strategy may over generalize to all situations when noise is not present, such that children tune out stimuli indiscriminately. In turn, this may lead to noise exposed children having poorer ability to sustain attention in the classroom, which may continue to affect concentration and learning over time even in the absence of noise exposure. This attentional theory has been supported by experimental studies on adults (Smith & Jones, 1992) and children (Evans & Lepore, 1993; Hygge, 1994). Simple tasks such as recognition (Hygge, 1994) and short-term memory (Evans *et al.* 1995) are not impaired by noise, suggesting that simple cognitive tasks, which require less attentional processing than complex tasks, are not affected by chronic noise exposure. Little recent field research has been conducted to examine the effects of chronic noise exposure on attention and the results have been equivocal (Moch-Sibony, 1984; Evans *et al.* 1995).

Areas of high environmental noise exposure are often also areas with high levels of social deprivation. As social deprivation is also a predictor of poor reading comprehension, it is potentially a confounding factor in the association of noise exposure and reading comprehension. However, we found that the association between noise exposure and reading comprehension remained after adjustment for social deprivation and social class. Previous studies have conducted testing in controlled environments using a sound-proof trailer (Evans *et al.* 1995) or using headphones (Evans & Maxwell, 1997) and have found reading deficits in school children. These results have been interpreted to suggest that chronic rather than acute noise exposure is the cause of the noise related reading deficits. However, it may be that acute noise during testing increases poorer reading performance. For the first time the effect of acute noise on cognitive performance was tested in a child sample who were chronically exposed to noise. The regression analyses, in the chronically high noise exposed children demonstrate variability in acute sound level does not influence cognitive performance. These analyses provide further evidence that impairments in cognitive function and increased annoyance are the result of chronic aircraft noise exposure.

The results suggest that the characteristics of individual schools may have a more powerful effect than noise exposure on reading comprehension. The issue of school standards or 'a school effect' is an obvious problem that may confound the reading comprehension results (Cohen *et al*. 1980; Rutter, 1985). This 'school effect' is likely to be a consequence of differences in the quality of individual schools (resources, head teachers, teachers, reputation and selection factors such as the children it attracts). Further research needs to increase the sample size of schools, obtain a measure of school quality and analyse the data at the school level as well as the individual level.

Short-term memory, did not differ between the high and low noise schools as expected. This result replicates the findings on noise and short-term memory around Munich Airport (Evans *et al*. 1995). Noise appeared to affect long-term memory recognition but not recall, but this was not a strong effect. We did not replicate the Munich results on long-term memory, which may be attributed to the new task used to measure long-term memory. In Munich the longitudinal long-term memory results provide very strong evidence that memory is a cognitive process affect by noise exposure (Hygge *et al*. 1996).

We found no effect of chronic noise exposure on motivation, teacher's reports of motivation in the classroom and child attributional style. This does not support the learned helplessness hypothesis previously used to account for the effects of noise on motivation (Cohen *et al*. 1986). It has been suggested that learned helplessness may become a generalized learned response that becomes manifest as low motivation during performance of all tasks regardless of the presence of noise (Cohen *et al*. 1980; Evans & Lepore, 1993; Evans *et al*. 1995). It is possible that the previous motivation findings were secondary to the cognitive results and that the performance task measured 'cognitive effort'. Task persistence as measured by the animal puzzles may assess a different aspect of motivation from learned helplessness.

The results of this study and previous literature (Cohen *et al*. 1980; Evans *et al*. 1995) indicate that chronic noise exposure is associated with impaired cognition and health over a range of functions in the child population as a whole. However, there may be individual differences across age and gender in these effects. Some children in the population may be more vulnerable to noise effects than others such as those from areas of social disadvantage, or with mental health problems, or learning difficulties.

In summary, our results suggest that noise exposure in children is associated with impaired reading comprehension and high levels of noise annoyance but not mental health problems in children. Taken together, the next step should be to confirm these findings by further research and to understand the mechanisms underlying the increased stress and impaired cognitive performance associated with chronic exposure to aircraft noise. Definitive conclusions about the effect of chronic aircraft noise exposure on reading comprehension cannot be drawn from the results of this study in isolation. However, the results are consistent with previous research (Cohen *et al*. 1980, 1981, 1986; Evans & Lepore, 1993; Evans *et al*. 1995; Evans & Maxwell, 1997). As environmental noise exposure is ubiquitous and increasing, the effects of noise on children's education may affect increasing numbers of children in the general population. This is potentially an important health and education problem.

A sincere thank you to the children, parents and teachers from the eight schools. We thank Val Beale, Jane Boyd, Robert Gibson and Patrick Shortt for help in data collection and noise measurement; and Maria Luz Herrero for coding. We also acknowledge the generous support of Professor Staffan Hygge, Colin Cobbing, Terry Gould, Professor Stuart Checkley and Dr Andrew Papadopoulos. This research was funded by a consortium of local authorities and health agencies around Heathrow Airport and was submitted as a public report for the Terminal 5 Public Inquiry. We thank them for their support.

APPENDIX 1

For acute sound levels at the time of testing in SEL on Day 1 and Day 2 are shown in the table below. Single event noise exposure level (SEL) is defined as a one second equivalent measure indicating the total energy of an event. For the Mean LAeq acute aircraft sound levels used in the cognitive and motivation analyses please contact the authors. These mean LAeq were measured for the duration of the each of the following tasks respectively: reading comprehension, long-term memory, short-term memory, motivation and annoyance.

Acute aircraft sound levels at the time of testing on Day 1 and Day 2 by class

	Mean SEL dBA		Max SEL dBA		Min SEL dBA		Number of events	
Class	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
High noise schools								
School 1								
Class 4	*	71	*	85	*	57	*	52
Class 5	72	71	86	86	61	57	52	57
School 2								
Class 4	70	66	77	70	61	59	14	28
Class 5	64	66	70	70	50	59	17	28
School 3								
Class 4	69	66	76	73	60	57	28	14
Class 5	69	71	77	74	56	67	14	4
School 4								
Class 4	77	0	86	0	59	0	52	0
Class 5	70	0	77	0	58	0	16	0
Low noise schools								
School 5								
Class 4	69	0	70	0	68	0	3	0
Class 5	0	0	0	0	0	0	0	0
School 6								
Class 4	0	67	0	67	0	67	0	1
Class 5	0	0	0	0	0	0	0	0
School 7								
Class 4	0	0	0	0	0	0	0	0
Class 5	0	0	0	0	0	0	0	0
School 8								
Class 4	0	0	0	0	0	0	0	0
Class 5	0	0	0	0	0	0	0	0

* Equipment malfunction.

REFERENCES

Averill, J. R. (1982). *Anger and Aggression An Essay on Emotion*. Springer Verlag: New York.

Bartley, M., Power, C., Blane, D., Davey-Smith, G. & Shipley, M. (1994). Birth weight and later socioeconomic disadvantage: evidence from the 1958 British cohort study. *British Medical Journal* **309**, 1475–1479.

Berglund, B. & Lindvall, T. (1995). Community Noise. *Archives of the Center for Sensory Research* **2**, 1–195.

Bobak, M. & Leon, D. A. (1992). Air pollution and infant mortality in the Czech Republic, 1968–88. *Lancet* **340**, 1010–1014.

Bronzaft, A. L. & McCarthy, D. P. (1975). The effects of elevated train noise on reading ability. *Environment and Behavior* **7**, 517–527.

Cohen, S. & Weinstein, N. (1981). Non-auditory effects of noise on behavior and health. *Journal of Social Issues* **37**, 36–70.

Cohen, S., Evans, G. W., Krantz, D. S. & Stokols, D. (1980). Physiological, motivational and cognitive effects of aircraft noise on children: moving from the laboratory to the field. *American Psychologist* **35**, 231–243.

Cohen, S., Evans, G. W., Krantz, D. S. & Stokols, D. (1981). Aircraft noise and children: longitudinal and cross-sectional evidence on adaptation to noise and the effectiveness of noise abatement. *Journal of Personality and Social Psychology* **40**, 331–345.

Cohen, S., Evans, G. W., Stokols, D. & Krantz, D. S. (1986). *Behavior, Health and Environmental Stress*. Plenum Press: New York.

Charman, T. (1994). The stability of depressed mood in young adolescents: a school based survey. *Journal of Affective Disorders* **30**, 109–116.

Evans, G. W. & Lepore, S. J. (1993). Non-auditory effects of noise on children. *Children's Environment* **10**, 31–51.

Evans, G. W. & Maxwell, L. (1997). Chronic noise exposure and reading deficits: the mediating effects of language acquisition. *Environment and Behavior* **29**, 638–656.

Evans, G. W., Kielwer, W. & Martin, J. (1991). The role of the physical environment in the health and well-being of children. In *New Directions in Health Psychology Assessment. Series in Applied Psychology: Social Issues and Questions* (ed. H. E. Schroeder), pp. 127–157. Hemisphere Publishing Corp.: New York.

Evans, G. W., Hygge, S. & Bullinger, M. (1995). Chronic noise and psychological stress. *Psychological Science* **6**, 333–338.

Evans, G. W., Bullinger, M. & Hygge, S. (1998). Chronic noise exposure and physiological response: a prospective study of children living under environmental stress. *Psychological Science* **9**, 75–77.

Fields, J. (1992). *Effect of Personal and Situational Variables on Noise Annoyance: With Special Reference to Implications for En Route Noise*. Research report for Federal Aviation Administration Office of Environment and Energy, obtainable from 800 Independence Avenue SW, Washington, DC 20591 and NASA Langley Research Center Hampton, VA 23665.

Fields, J. M., de Jong, R. G., Brown, A. L., Flindell, I. H., Gjestland, T., Job, R. F. S., Kurra, S., Lercher, P., Schuemer-Kohrs, A., Vallet, M. & Yano, T. (1997). Guidelines for reporting core information from community noise reaction surveys. *Journal of Sound and Vibration* **206**, 685–695.

Fincham, F. D., Kokoda, A. & Sanders, R. (1989). Learned helplessness, test anxiety and academic achievement: a longitudinal analysis. *Child Development* **60**, 138–145.

Glass, D. C. & Singer, J. E. (1972). *Urban Stress: Experiments on Noise and Social Stressors*. Academic Press: New York.

Goodman, R. (1994). A modified version of the Rutter Parent Questionnaire including extra items on children's strengths: a research note. *Journal of Child Psychology and Psychiatry and Allied Disciplines* **35**, 1483–1494.

Goodman, R. (1997). The strengths and difficulties questionnaire: a research note. *Journal of Child Psychology and Psychiatry* **38**, 581–586.

Hagley, F. (1987). *Suffolk Reading Scale*. NFER-NELSON: Windsor.

Heft, H. (1985). High residential density and perceptual cognitive development. An examination of the effects of crowding and noise in the home. In *Habitats for Children* (ed. J. F. Wohwill and W. Van), pp. 39–76. Erlsbaum: Hillsdale, NJ.

Hygge, S. (1994). Classroom experiments on the effects of aircraft, road traffic, train and verbal noise presented at 66 dBA Leq, and of aircraft and road traffic presented at 55 dBA Leq, on long term recall and recognition in children aged 12–14 years. In *Noise as a Public Health Problem: Proceedings of the Sixth International Congress*, *Vol. 2* (ed. M. Vallet), pp. 531–538. INRETS: Arcueil, France.

Hygge, S., Evans, G. W. & Bullinger, M. (1996). The Munich airport noise study: cognitive effects on children from before to after the change over of airports. In *Proceedings of Inter-Noise '96*. *Book 5*, pp. 2189–2192. Institute of Acoustics: Liverpool.

Job, R. F. S. (1988). Community response to noise: a review of factors influencing the relationship between noise exposure and reaction. *Journal of the Acoustical Society of America* **83**, 991–1001.

Job, R. F. S. (1996). The influence of subjective reactions to noise on health effects of noise. *Environment International* **22**, 93–104.

Kaslow, N. J. & Nolen-Hoeksema, S. (1991). Children's Attributional Style Questionnaire – Revised (CASQ-R). Unpublished manuscript, Emory University, Atlanta.

Kazdin, A. E. (1981). Assessment techniques for childhood depression: a critical appraisal. *Journal of American Academic Child Psychiatry* **11**, 358–375.

Kirschbaum, C. & Hellhammer, D. H. (1994). Salivary cortisol in psychoneuroendocrine research: recent developments and applications. *Psychoneuroendocrinology* **19**, 313–333.

Kirschbaum, C., Strasburger, C. J., Jammers, W. & Hellhammer, D. H. (1989). Cortisol and behavior: Adaptation of radioimmunoassay kit for reliable and inexpensive salivary cortisol determination. *Pharmacology Biochemistry and Behavior* **34**, 747–751.

Kovacs, M. & Beck, A. T. (1977). An empirical-clinical approach towards a definition of childhood depression. In *Childhood Depression* (ed. J. G. Schulterbrabdt and A. Raskins), pp. 1–25. Raven Press: New York.

Moch-Sibony, A. (1984). Study of the effects of noise on personality and certain psychomotor and intellectual aspects of children, after a prolonged exposure. *Travail Humane* **47**, 155–165.

Nolen-Hoeksema, S., Girgus, J. S. & Seligman, M. E. (1986). Learned helplessness in children: A longitudinal study of depression, achievement and explanatory style. *Journal of Personality and Social Psychology* **51**, 435–442.

OPCS (1989). *General Household Survey 1987*. HM Stationery Office: London.

Poustka, F., Eckermann, P. & Schmeck, K. (1992). Effect of aircraft noise and psychosocial stressors on mental disturbances of children and adolescents: an epidemiological survey in Westphalia. In *Developmental Psychopathology* (ed. H. Remschmidt and M. H. Schmidt), pp. 83–96. Hogrefe & Huber Publishers: Gottingen, Germany.

Reynolds, C. R. & Richmond, B. O. (1978). What I think and feel: a revised measure of the Children's Manifest Anxiety. *Journal of Abnormal Child Psychology* **6**, 271–280.

Rodin, J. (1977). Crowding, perceived choice and response to controllable and uncontrollable outcomes. *Journal of Experimental Social Psychology* **12**, 564–578.

Rutter, M. (1985). Family and school influences on cognitive development. *Journal of Child Psychology and Psychiatry* **26**, 683–704.

Rutter, M., Tizard, J. & Whitmore, K. (1970). *Education*, *Health and Behaviour*. Longman: London.

Saegert, S. (1981). Environment and children's mental health: residential density and low income children. In *Handbook of Psychology and Health*, *Vol. 2* (ed. A. Baum and J. E. Singer), pp. 247–271. Erlbaum: Hillsdale, NJ.

Smith, A. P. & Jones, D. M. (1992). Noise and Performance. In *Handbook of Human Performance*, *Vol. 1* (ed. D. M. Jones and A. P. Smith), pp. 1–28. Academic Press: London.

Stansfeld, S. A. (1992). *Noise*, *Noise Sensitivity and Psychiatric Disorder*. *Psychological Medicine*, *Monograph 22*. Cambridge University Press: Cambridge.

Stanfeld, S. A. & Haines, M. M. (1997). *The Schools Environment and Health Study – Pilot Study Report on Tests Conducted between March 1996 and July 1996*. A report for the Public Inquiry into the application by BAA plc and Heathrow Airport Limited for the development of a fifth terminal and associated facilities at Heathrow Airport: London.

Stansfeld, S. A., Sharp, D. S., Gallacher, J. & Babisch, W. (1993). Road traffic noise, noise sensitivity and psychological disorder. *Psychological Medicine* **23**, 977–985.

Stansfeld, S. A., Gallacher, J., Babisch, W. & Shipley, M. (1996). Road traffic noise and psychiatric disorder: prospective findings from the Caerphilly Study. *British Medical Journal* **313**, 266–267.

Tarnopolsky, A. & Morton-Williams, J. (1980). *Aircraft Noise and Prevalence of Psychiatric Disorders*, *Research Report*. Social and Community Planning Research: London.

Townsend, P., Phillimore, P. & Beattie, A. (1989). *Health and Deprivation*. Routledge: London.

Weinstein, N. D. (1982). Community noise problems: evidence against adaptation. *Journal of Environmental Psychology* **2**, 87–97.