

MENTAL HEALTH

A follow-up study of effects of chronic aircraft noise exposure on child stress responses and cognition

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Background Children are a high-risk group vulnerable to the effects of chronic aircraft noise exposure. This study examines the effects of aircraft noise exposure on children's health and cognition around London Heathrow airport and tests sustained attention as an underlying mechanism of effects of noise on reading and examines the way children adapt to continued exposure to aircraft noise.

Methods In this repeated measures epidemiological field study, the cognitive performance and health of 275 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). The children first examined at baseline were examined again after a period of one year at follow-up. Health questionnaires and cognitive tests were group administered to the children in the schools.

Results and Conclusions At follow-up chronic aircraft noise exposure was associated with higher levels of annoyance and perceived stress, poorer reading comprehension and sustained attention, measured by standardized scales after adjustment for age, social deprivation and main language spoken. These results do not support the sustained attention hypothesis previously used to account for the effects of noise on cognition in children. The reading and annoyance effects do not habituate over a one-year period and do not provide strong evidence of adaptation.

Keywords Chronic aircraft noise exposure, children, cognition and stress responses, adaptation, repeated measures epidemiological field study

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Consistent associations between chronic aircraft noise exposure and impaired cognition and stress responses in children have been found in cross-sectional studies around international airports namely: Los Angeles;¹ Munich;^{2,3} New York;⁴ and London.⁵ Important questions remain unanswered about the long-term effects of persistent aircraft noise exposure, underlying causal mechanisms, and the nature of the noise

effects. It is still unknown whether prolonged exposure to aircraft noise results in increasing adverse effects, or whether the effects remain constant, or the effects lessen or disappear. Cohen and colleagues⁶ reported a one-year follow up of their baseline sample of school children around Los Angeles Airport¹ but unfortunately due to a low response rate in the noisy schools the within-subjects analyses were difficult to interpret.⁶ In this repeated measures study we report follow-up data from the same sample of children first examined at baseline where cross-sectional main effects were found on reading and noise annoyance.⁵ By following these children up after a period of a year, child adaptation will be examined to provide a preliminary answer to how children are affected by persistent noise exposure in terms of reading and noise annoyance.

Chronic exposure to environmental noise may be a stressor because it decreases expectancies for control and increases susceptibility to helplessness.⁷ However, there is little empirical evidence to support the key assumption of this theory that the

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children exposed to high levels of environmental noise are, in fact, stressed. Furthermore, understanding of the mechanisms underlying child noise effects is limited. Only three studies^{4,5,8} have directly tested the mediating role of a hypothesized factor and no study has tested the attention mediation hypothesis. Aircraft noise has a main direct effect on sustained attention,^{9–14} however, it is also possible that sustained attention also acts as a mediating factor between noise exposure and cognitive impairments.

It was hypothesized that the effects of aircraft noise exposure found on reading comprehension and noise annoyance at baseline⁵ would be replicated in the same sample of school children who were tested at follow-up one year later. It was also hypothesized that: (1) chronic aircraft noise exposure produces an increased delay in reading comprehension over a period of a year compared to pupils not exposed to aircraft noise during that year and (2) that chronic aircraft noise exposure in children would be associated with impairments in sustained attention and high levels of self-reported stress. Sustained attention was tested as a mediating factor in the association between noise exposure and reading impairment.

Methods

Design

The school performance and health of children attending four schools in a high-aircraft noise-impact urban area (16-h outdoor Leq >66 dBA) were compared with those of children from four matched control schools in low-aircraft noise-impact urban areas (16-h outdoor Leq <57 dBA) around Heathrow Airport in West London (for full details of design and methods⁵). Children first examined in 1996 were examined again one year later in 1997. The schools were initially chosen such that children were matched across high and low aircraft noise as much by: age; sex; sound level at the school from non-aircraft sources; existing noise protection in the schools; and socio-economic status and ethnicity of the school's electoral wards. The performance and health measures were group administered in the classrooms.

Participants and response rate

At baseline in 1996, 340 pupils participated. At follow-up the overall child response rate was 81% of the baseline sample across the eight schools. Of the original sample of 340, 10% (n = 35) declined to take part in 1997; 6% (n = 19) had moved; and 3% (n = 11) were away at the time of testing. The response rate did not differ between high- and low-noise exposed children. The follow-up participants were 275 fifth (n = 121) and sixth (n = 154) class pupils (mean age = 10 years and 8 months, 52% girls, 48% boys) of the baseline sample. In all, 148 attended schools exposed to high levels of aircraft noise and 127 attended schools exposed to low levels of aircraft noise. The socio-demographic characteristics of the declining sample and the sample that had moved were not significantly different to the participating sample in terms of sex, race, age and social class.

Stress response and health outcomes measures

Annoyance

Noise annoyance was measured with seven child adapted standard questions.¹⁵ These questions assessed the level of annoyance

on a four-point Likert scale (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). Aircraft noise at school was the annoyance item used in the analyses with the higher the score the higher the noise annoyance.

Lewis Child Stress Scale

Child stress was measured with the Lewis child stress scale.¹⁶ The scale consists of 20 stress-provoking circumstances that were generated through interviews with children concerning sources of stress in their lives. The 20 items included situations that would make children feel bad (e.g. not having homework done on time), nervous (e.g. changing schools) or worried (e.g. not getting along with your teacher). The 20 items were repeated in two subscales. The first scale asks the children to rate how bad would they feel if each of the 20 situations happened to them on a five-point scale: 'not bad'–'terrible'. The second scale asks the children to rate how often each of the 20 situations happened to them on a five-point scale: 'never'–'all the time'. Three scores were used in the analysis: **(1) a perceived stress score:** an addition of the first scale values, how bad would they feel if an event happened to them, **(2) a frequency score:** an addition of the second scale values to calculate how often negative life events had occurred, **(3) an overall stress score:** calculated by individually multiplying each item from the first scale ('how bad they would feel') by the second scale (frequency of occurrence) and summing the total for the 20 items. Normative data from 2480 fifth grade American students found high internal consistency ($\alpha = 0.82$).¹⁶

Depression

Depression was measured with the short version of the Child Depression Inventory (CDI,¹⁷ modified for an English sample¹⁸).

Anxiety

Anxiety was measured with the Revised Child Manifest Anxiety Scale (CMAS).¹⁹

Cognition and performance outcome measures

Reading comprehension

Reading comprehension was measured using the UK standardized Suffolk Reading Scale²⁰ Level 2.

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 A²¹). 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.²¹ 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 Scale²² by incorporating income, crowding, home ownership and unemployment in a single scale (these data were collected from parents). The number of indicators of household deprivation reported out of these four indices were summed and a total deprivation score calculated.²²

Household deprivation was preferred as a confounding factor because social class was not considered to be a satisfactory indicator of social disadvantage.²³ Main language spoken at home was collected from the children, parents and school. Age was collected from school records and the parents.

Procedures

Testing at the schools was conducted the same way as baseline (for full procedural details⁵). The group administered testing was conducted on three days each a week apart, counter-balanced for questionnaire order and time of day across noise exposure in the classrooms. Measurements at individual schools were carried out inside classrooms to assess indoor sound levels of aircraft noise during testing using a sound level meter mounted on a tripod and a portable DAT recorder.

Statistical analysis

Three potential confounding factors were adjusted for in the analyses namely: age, main language spoken at home and household deprivation. Main language spoken at home was reported by parents and children and is a variable with two levels: English and non-English. Analyses of covariance (ANCOVA) adjusting for baseline performance were used to assess the noise-effects over time. The within-subjects unadjusted model adjusts for baseline performance only and the fully adjusted model also adjusts for age, main language spoken at home and household deprivation. A procedural error occurred earlier at baseline, when one control school did not supply a representative sample class but a class of lower ability (for full discussion⁵). Therefore, the results will be presented on all eight schools and on the seven schools excluding the school with the biased sample selection for the significant main effects in the result section text with means, F-test statistics and *P*-values. All statistical tests are two tailed and the alpha value was set at 0.05.

Results

Descriptive results

The high- and low-noise follow-up sample were well matched across noise levels for class at school and sex (Table 1). The

high noise school sample had a higher proportion of non-white pupils and pupils with languages other than English as the main language spoken at home than the low-noise sample. The high-noise sample also had a slightly higher proportion of pupils from manual social class households indicated by the registrar general's classification and pupils from deprived households than the low noise sample (Table 1).

Cross-sectional effects at follow-up: stress responses and cognitive performance

All results presented have been adjusted for age, deprivation and main language spoken (Table 2).

Annoyance

Chronic exposure to high levels of aircraft noise was associated with higher levels of annoyance in the analyses of the eight schools (high-noise [HN] mean = 1.00, low-noise [LN] mean = 0.58, $F(1,206) = 9.75$, $P = 0.002$) and the seven schools (LN mean = 0.56, $F(1,188) = 8.8$, $P = 0.003$) (Table 2).

Self-reported stress

Chronic exposure to aircraft noise was associated with higher levels of perceived stress in the analyses of the eight schools (HN mean = 3.5, LN mean = 3.22, $F(1,185) = 9.57$, $P = 0.002$) and in the seven schools (LN mean = 3.19, $F(1,168) = 10.2$, $P = 0.002$, Table 2). Chronic exposure to aircraft noise was not associated with the prevalence of stressful life events nor with the total stress score (Table 2).

Anxiety and depression

The two groups did not significantly differ in mean scores of anxiety and depression (Table 2), nor 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.

Reading comprehension

Chronic exposure to aircraft noise had no significant effect on reading comprehension in the analyses of the eight schools. 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 = 100.63, LN mean = 105.21, $F(1,178) = 5.00$, $P = 0.027$, Table 2).

Table 1 The socio-demographic characteristics of the high- and low-noise child follow-up samples: frequencies and proportions, continuity correction χ^2 *P*-value

Socio-demographic characteristic	High noise (N = 148)	Low noise (N = 127)	χ^2 <i>P</i> -value
Year 5	66 (45%)	55 (43%)	
Year 6	82 (55%)	72 (57%)	$P = 0.93$
Girls	74 (50%)	69 (54%)	
Boys	74 (50%)	58 (46%)	$P = 0.52$
White	49 (36%)	111 (89%)	
Non-White	86 (64%)	14 (11%)	$P = 0.0001$
English—Main language spoken at home	90 (66%)	116 (94%)	
Non-English	46 (34%)	8 (6%)	$P = 0.0001$
Non-manual social class (1,2,3N)	42 (47%)	49 (58%)	
Manual social class (3M,4,5)	48 (53%)	36 (42%)	$P = 0.19$
Not deprived	68 (53%)	70 (63%)	
Deprived	60 (47%)	41 (37%)	$P = 0.16$

Note. 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.

Table 2 Stress response and cognitive mean scores, difference score at follow-up fully adjusted for age, deprivation and main language spoken in the four high-noise schools and the three low-noise schools (excluding the procedural error school)

Outcome	Adjusted mean		Difference score (95% CI)	P-value
	Four high-noise schools	Three low-noise schools		
Stress responses				
Annoyance	1.00	0.56*	−0.44 (−0.73, −0.15)	P = 0.003
Self-reported stress				
(Perceived stress score)	3.50	3.19*	−0.31 (−0.5, −0.12)	P = 0.002
(Frequency score)	1.89	1.96	0.07 (−0.07, 0.22)	P = 0.33
(Total score)	6.56	6.20	−0.36 (−1.04, 0.33)	P = 0.31
Depression (CDI) ^a	4.50	4.58	0.08 (−1.27, 1.42)	P = 0.92
Anxiety (CMAS) ^b	10.94	11.12	0.18 (−2.05, 2.38)	P = 0.88
Cognition				
Suffolk Reading Comprehension Scale	100.63	105.21*	4.58 (0.54, 8.63)	P = 0.027
Sustained attention score task	8.44	8.91*	0.47 (0.01, 0.93)	P = 0.04

^a Child Depression Inventory.^b Child Manifest Anxiety Scale.

* P < 0.05 for comparison with the four high-noise schools.

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

Sustained attention

Chronic exposure to high levels of aircraft noise was associated with poorer sustained attention in the eight schools (HN mean = 8.44, LN mean = 9.01, $F(1,201) = 8.01$, $P = 0.005$) and in the seven schools (LN mean = 8.91, $F(1,183) = 4.16$, $P = 0.04$, Table 2).

Within-subjects analyses—the effects of noise over time

Reading comprehension

After adjusting for baseline performance, performance at follow-up was significantly different between the high-noise and low-noise children in the eight (HN mean = 100.1, LN mean = 101.9, $F(1,225) = 4.57$, $P = 0.03$, Table 3) and seven schools (HN mean = 101.1, LN mean = 103.0, $F(1,204) = 4.8$, $P = 0.03$, Table 3). However, after further adjustments are made for age, main language spoken and deprivation, the difference in reading comprehension in both the seven and eight schools fails to reach significance (Table 3). The inability to find a significant effect after full adjustment might be due to a reduction in statistical power, because of a drop in sample size. Analyses were conducted in reduced samples with scores taken out for children with missing values for both deprivation and main

language spoken. The within-subjects reading analysis was conducted in these samples and the results were: reduced sample for main language spoken (difference score = 1.6, $F(1,193) = 3.41$, $P = 0.06$) and the reduced sample for deprivation (difference score = 1.4, $F(1,173) = 2.48$, $P = 0.12$). In the reduced samples the main effect found in the full sample (difference score = 1.9) is of similar magnitude but is no longer significant.

Noise annoyance

In the analyses of the eight schools after adjusting for baseline noise annoyance, noise annoyance at follow-up was significantly different between the high-noise and low-noise children (HN mean = 0.93, LN mean = 0.67, $F(1,245) = 5.42$, $P = 0.02$, Table 3). This did not remain significant after further adjustment was made for age, deprivation and main language spoken (Table 3). There was no significant effect in the seven schools (Table 3).

Testing the sustained attention hypothesis

To test this hypothesis, sustained attention score was entered as a covariate in an ANCOVA model (independent variable—school noise level: high or low, dependent variable—reading comprehension score). Sustained attention did not explain the significant association between aircraft noise exposure at school

Table 3 Difference score from the within-subjects ANCOVA models (1) adjusting for baseline performance on follow-up reading comprehension and noise annoyance performance and (2) fully adjusted for age, main language spoken and deprivation in the eight and seven schools (excluding the procedural error school)

	8 schools comparison		7 schools comparison	
	Difference score (95% CI)	P-value	Difference score (95% CI)	P-value
Performance at follow-up				
Reading Comprehension Score at follow-up				
Adjusted for baseline performance	1.8* (0.14, 3.34)	0.03	1.9* (0.19, 3.6)	0.03
Fully adjusted	0.8 (-1.0, 2.7)	0.372	1.2 (-0.87, 3.15)	0.266
Noise annoyance at follow-up				
Adjusted for baseline performance	-0.26* (-0.49, -0.04)	0.02	-0.22 (-0.47, 0.01)	0.069
Fully adjusted	-0.18 (-0.4, 0.07)	0.16	-0.18 (-0.46, 0.09)	0.197

* P < 0.05.

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

and reading comprehension. This is indicated by the fact that the significance level of the main reading effect in the seven schools was not altered by the adjustment for sustained attention ($F(1,203) = 8.51$, $P = 0.004$).

Noise exposure

At follow-up measurements were taken at individual schools to assess indoor sound levels of aircraft noise during testing. Acute levels of aircraft noise at the time of testing were measured in single event noise exposure levels (SEL dBA). The SEL is defined as the total sound energy of an event expressed as a one-second equivalent and is a measure of sound energy which allows for the direct comparison of sound events of differing duration. Acute aircraft noise was only present at the testing of one high noise school over the two testing sessions. School 4 had a mean of 65.7 SEL dBA with 3 aircraft events on day 1 of testing and a mean 64.2 SEL dBA with 41 events on day 2. This indicates that there was very little difference between high and low chronic aircraft noise exposed schools in terms of acute aircraft noise exposure during testing. This is in contrast to the high level of acute interference reported in the high noise schools at baseline.⁵

Discussion

There were five main findings in this study. First, the associations between chronic aircraft noise exposure and reading comprehension, noise annoyance and mental health were replicated at follow-up. Second, the within-subjects analyses indicate that children's development in reading comprehension may be adversely affected by chronic aircraft noise exposure. Noise annoyance remained constant over a year with no strong evidence of habituation. The effect of aircraft noise on children's progress in reading over time may be influenced by socio-demographic factors. Third, the association between aircraft noise exposure and reading comprehension could not be accounted for by the sustained attention mediation hypothesis. Fourth, chronic aircraft noise exposure was associated with poorer sustained attention in children. Fifth, chronic aircraft noise exposure was associated with higher levels of self-reported perceived stress in children. These results provide evidence that aircraft noise adversely affects the performance and health of school children and that these effects do not habituate over time.

Adaptation

After adjustment for baseline reading performance a significant noise effect on reading remained at follow-up indicating that further noise exposure over time was associated with an increase in the size of the difference in reading impairments in the high noise exposed group compared with the control sample. However, the within-subjects reading result was not conclusive because socioeconomic factors may influence reading comprehension. After statistical adjustment was made for deprivation and main language spoken at home on the association between noise and reading progress, the size of the effect was reduced and became non-significant. The results of the analyses in the reduced samples suggest that regardless of whether main language spoken or deprivation were, or were not, confounding factors, the sample size was reduced to such an extent that when adjustments were

made for language and deprivation the 'noise effect' would be lost. Therefore, it must be concluded that it is still possible that socioeconomic factors may have confounded the relationship because there were insufficient socio-demographic data to test this reliably.

The Los Angeles Study and the present study are limited because the impact of previous experience of exposure to aircraft noise is unknown and a self-selected high-noise sample cannot be ruled out. In the case of this study, it is possible that children with poorer performance tended to remain in the high-noise exposed areas because their parents were less socially advantaged, hence less mobile. If the effects of social disadvantage on reading comprehension were partly mediated through noise exposure, statistically adjusting for social deprivation may constitute an over adjustment. The issue of long-term habituation to environmental stressors has only started to be addressed, and further repeated measures longitudinal research is still required to address these problems.

Sustained attention mediation hypothesis

The results of this study do not support the sustained attention mediation hypothesis because adjustment for sustained attention did not influence the significant association between aircraft noise at school and reading comprehension. Attentional processes have been hypothesized as mediators in noise-related memory impairments more than reading effects. Adult noise studies on memory have been interpreted as indicative of attention narrowing or focusing on dominant stimuli.²⁴ Greater attention to more central cues could lead to poorer encoding of more peripheral material when greater processing demands are placed on memory than would be expected on a reading task. So it is possible that specific cognitive mechanisms may only apply to specific noise effects on child cognition. Further research should test and refine the other theories to account for these reading effects, especially testing psycholinguistic mechanisms where there is preliminary evidence of mediation by impairment of speech perception⁴ and auditory discrimination.⁸ Better understanding of the mechanisms by which noise impairs reading may allow for more effective counter measures to the effects of noise.

Annoyance

The annoyance response remained constant over time and there was little evidence that the effect increases over time. The long-term health consequences of chronic annoyance are unknown. This finding that noise annoyance, a stress response, remains persistent is in potential contradiction to the conclusions from the follow-up study around Los Angeles⁶ where the data were interpreted to indicate some habituation of physiological stress response. It is indeed possible that the annoyance response may be affected by chronic noise in a different way than a physiological stress response. It is also possible that response style related to coping with environmental stress influences reports of annoyance, more than physiological responses. Future longitudinal research should measure both noise annoyance and physiological stress responses to examine habituation or potentiation as well as the interaction between self-reported stress and biological stress markers. Adaptive behaviours may reduce the immediate stress response in the form of physiological adaptation, but the coping process itself may have

adverse health effects that might be measured through self-reported stress.²⁵

Perceived stress

Children chronically exposed to high levels of aircraft noise had higher levels of perceived stress even after adjustment for age, deprivation and main language spoken indicating that the high noise children reported they would have felt more stressed than the control children if these stressful life events were to occur in their lives. Interestingly, the children across the two groups did not differ in terms of reporting actual stressful events. This suggests some specificity of effect in relation to perceived stress and that children did not answer according to a trait of general negative affectivity. It is possible that this perceived stress scale also partly measures perceived coping ability or worrying and high scores predict sensitivity to stress.

Our results show for the first time that children chronically exposed to aircraft noise do have higher levels of self-reported stress, which complements the previous psychophysiological stress data (catecholamine secretion and raised blood pressure).^{1–3} This result is important because it lends support to the underlying assumption that chronic exposure to aircraft noise is subjectively stressful. This self-reported stress response needs to be refined by further measures, to ascertain what these children are stressed about—is it their environment? Consistent with the baseline results,⁵ levels of depression and anxiety did not differ between the two samples. These affective results taken together suggest that chronic exposure to aircraft noise produces annoyance and general stress responses rather than sub-clinical mental health problems such as depression or anxiety.

Conclusions

The results of this repeated measures study are not conclusive. Nevertheless, they provide stronger evidence than previous studies to suggest that noise exposure affects child cognition and stress responses and that these effects do not habituate over a one-year period. The fact that the main reading effect remained constant between baseline and follow-up, despite marked variation in the acute noise interference at testing, provides further evidence that the cognitive impairments are due to chronic exposure rather than acute interference at the time of testing. These results do not support the sustained attention hypothesis previously used to account for the effects of noise on cognition in children. The within-subjects analyses indicate that children's development in reading comprehension may be adversely affected by chronic aircraft noise exposure. Noise annoyance remains constant over a year with no strong evidence of habituation. Further research should look at the long-term implications of these effects and examine further underlying mechanisms.

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KEY MESSAGES

- this repeated measures epidemiological field study examines the effects of aircraft noise exposure on primary school children's health and cognition around London Heathrow airport.
- chronic exposure to aircraft noise was associated with impairments in reading and attention and raised annoyance and perceived stress.
- the results provide evidence that aircraft noise adversely affects the performance and health of school children and that these effects do not habituate over time.

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