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Multilevel modelling of aircraft noise on performance tests in schools around Heathrow Airport London

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Study objective: To examine the effects of chronic exposure to aircraft noise on children's school performance taking into account social class and school characteristics.
Design: This is a cross sectional study using the National Standardised Scores (SATs) in mathematics, science, and English (11 000 scores from children aged 11 years). The analyses used multilevel modelling to determine the effects of chronic aircraft noise exposure on childrens' school performance adjusting for demographic, socioeconomic and school factors in 123 primary schools around Heathrow Airport. Schools were assigned aircraft noise exposure level from the 1994 Civil Aviation Authority aircraft noise contour maps.
Setting: Primary schools.
Participants: The sample were approximately 11 000 children in year 6 (approximately 11 years old) from 123 schools in the three boroughs surrounding Heathrow Airport.
Main results: Chronic exposure to aircraft noise was significantly related to poorer reading and mathematics performance. After adjustment for the average socioeconomic status of the school intake (measured by percentage of pupils eligible for free school meals) these associations were no longer statistically significant.
Conclusions: Chronic exposure to aircraft noise is associated with school performance in reading and mathematics in a dose-response function but this association is confounded by socioeconomic factors.

Previous studies examining the association between chronic noise exposure at school and at home, or both, with standardised reading and other intellectual achievement tests have found preliminary evidence of a relation between environmental noise exposure and school performance.[1–6] Green and colleagues,[7] in the most comprehensive study to date, analysing a large database of school achievement tests, studied 8240 grades from children in years 2–6 of 362 schools (geo-coded into five aircraft noise bands) around airports in New York City. They found a dose-response relation that indicated that the percentage reading below grade level increased as noise level increased. Two limitations of this study will be addressed in the present study. Firstly, the reading outcome was a dichotomous variable (above/below grade level), which is not as sensitive as a continuous performance measure taken at the individual level. Secondly, the performance outcomes in the analysis did not take account of the clustered nature of the data by using performance scores at the individual level.

The results of previous studies examining the effects of aircraft noise on child cognitive performance raise further questions, two of which will be addressed in this study. Firstly, were associations found previously confounded by social class and school characteristics?

It is possible that previous noise effects may be confounded by school effects and by social deprivation.[8 9] A school effect means that the characteristics of individual schools may have a more powerful effect than noise exposure on school performance. School quality and social deprivation are known to adversely influence school performance and these factors have complex inter-relations with each other and with noise exposure. Pupils from socially deprived areas have lower educational attainment than their counterparts from less disadvantaged areas.[10] Children from disadvantaged backgrounds are more likely than other children to live in a worse physical environment.[11] Therefore, poorer quality schools are more common in socially deprived areas, which are also more likely to be exposed to high levels of aircraft noise. Thus there is a need to adjust for the socioeconomic characteristics of the local catchment area, as they may well confound the relation between noise exposure and educational attainment.

Secondly, there is the question of whether the aircraft noise exposure affects school performance uniformly or whether impairments are more likely to be found in language-based tasks. Generally, it has been assumed that language-based tasks (such as reading and comprehension) are more affected by noise exposure than non-language based tasks (mathematics and science). While there is a growing number of studies to suggest that noise exposure does affect reading[5 12 13] there are few comparative data to suggest that noise exposure affects language-based tasks more than other cognitive tasks. To demonstrate that noise exposure affects language-based tasks more than other cognitive outcomes, a comparative multivariate research design is required to make divergent predictions about the effects of noise on the performance outcomes.

The specific aim of this study is to examine the effect of chronic exposure to aircraft noise on school performance outcomes in mathematics, English (reading, writing, spelling, and handwriting) and science in 11 year old children in schools exposed to a range of aircraft noise exposure. It is hypothesised that chronic aircraft noise exposure will be associated with poorer performance in English and reading in a dose-response function. Noise effects will be larger for the reading performance than for spelling, writing, and handwriting performance. No effects are expected on the control outcomes of mathematics and science.

METHODS

Design

This is a cross sectional study of aircraft noise exposure and school performance in a sample of students using the 1996 and 1997 results of National Standardised Scores (SATs) for Key Stage 2 in mathematics, science, and English. The analyses used multilevel modelling to take account of the

Table 1 A summary of the variables and precise outcomes in the analyses

School level factors	Individual level factors
Aircraft noise exposure	English performance score
Percentage of pupils eligible for a free school meal	English sub-tests: spelling (test 1); handwriting (test 2); creative writing (test 3); reading (test 4).
Percentage of pupils statemented with special needs	Mathematics performance score
Percentage of pupils with English as a second language	Science performance score
Type of school (government, church, grant maitained)	Sex
	Year of testing (1996 or 1997)
	Date of birth (only for 1997 sample)

hierarchical or clustered sample design (pupils within schools) and to permit adjustment for both pupil and school level factors. Schools were assigned aircraft noise exposure level from the 1994 Civil Aviation Authority aircraft noise contour maps. (For a summary of all variables see table 1).

Sample
The sample were approximately 11 000 children in year 6 (approximately 11 years old), the final year of primary school, who completed the Key Stage 2 SATs examinations in 1996 and 1997 from 123 government, grant maintained, and church primary schools in the three boroughs surrounding Heathrow Airport (Hillingdon, Hounslow, and Windsor and Maidenhead). These areas were chosen because they surround Heathrow Airport, and within each area schools are exposed to a large range of aircraft noise exposure. In the analyses the following numbers of pupils were included: 10 998 scores for English (10 957 for spelling; 10 957 for handwriting; 10 957 for creative writing; 10 957 for reading); 11 105 scores for mathematics; 11 163 for science. The numbers differ slightly as some test results were missing or invalid for a very small number of pupils.

Aircraft noise exposure estimation
The key exposure examined in this study was aircraft noise (air noise, rather than ground noise) from the aircraft taking off from, and landing at, Heathrow Airport. Noise exposure levels were taken from the published 1994 Civil Aviation Authority dBA Leq, 16hr (92 days) contour maps indicating the average continuous equivalent sound level of aircraft noise within a particular area for 16 hour daily periods during 15 June to 15 September. Each school was classified into one of eight noise exposure levels depending on which noise contour band (dBA Leq 16 hour) the school was sited: 1= <54, 2=54>57, 3= 57>60, 4= 60>63, 5= 63>66, 6= 66>69, 7= 69>72, 8= >72.

School performance
SATs of national curriculum assessments for Key Stage 2 are taken by all British school children when they are in year 6. These examinations are nationally standardised and marked externally for English, mathematics, and science. School averages are public, but individual grades are available on request from the Department for Education and Employment (DfEE). The school and individual level scores for 1996 and 1997 were obtained in ASCII format from DfEE. The examinations involve each child completing two exams for mathematics (which produces one total score), two for science (which produces one total score), and four exams for English (spelling, handwriting, writing, and reading). Individual final raw scores that range from 0 to 100 are calculated by averaging performance across exams for each of mathematics, science and English.

Gender and age
Individual dates of birth of the 1997 sample were obtained from the local education authorities. Gender and year group at school of each individual child were obtained from DfEE.

Social deprivation
At the school level, "percentage of pupils eligible for free school meals" was used as a proxy measure for social deprivation. Family on social security benefit is the criteria for entitlement for free school meal. Previous research in Britain suggests that "percentage of pupils eligible for free school meals" is a reliable indicator of social disadvantage for the precise catchment of pupils attending the school because there is a significant correlation between the free meal ratio and a range of census indicators representative of social economic status.[14 15]

Main language spoken at home
Percentages were obtained from DfEE for children who have English as a second language at the school level from the 1996 and 1997 school census data.

School characteristics
Percentage of children within each school who are statemented as having special needs were obtained from DfEE from the 1996 and 1997 school census data. The special need can either be a behavioural problem, a learning difficulty or a learning disability and is assessed by a multidisciplinary team. There are different levels of statementing, which reflect differing levels of child educational need. The data received from the DfEE indicate percentage of children statemented as having a special need at the school level. School type was classified as either government, grant maintained,church, or a school for children with special needs.

Statistical procedures
The analysis used multilevel modelling[16] as the SATs data are hierarchical with pupils (level 1 units) clustered within schools (level 2 units). Multilevel modelling makes best (or statistically efficient) use of these data rather than having to choose whether to analyse at the individual or school level, neither of which is satisfactory.[17] The multilevel method produces correct standard errors and significance tests as the analysis takes account of the clustered nature of the data. Both variables at the school level (for example, type of school) and the pupil level (for example, age) can be included in the same model. Finally, one can see whether noise effects "explain" any of the variation in SATs scores between schools.

The multilevel models were fitted to the data using the statistical package, Mln.[18] Models including the possible explanatory variables were fitted. The output from these analyses is in two parts: (1) fixed coefficients for each of the explanatory variables in the model; (2) random parameters that describe the unexplained variability in SATs scores after taking account of the explanatory variables (section 2, Results). The fixed coefficients, with the most important being the coefficient for noise level are interpreted just as in ordinary multiple regression. There are two random parameters, one for the level 2 (school) variation and one for the level 1 (pupil) variation. These can be compared across models containing different explanatory variables to see whether these variables "explain" any of the variability in SATs scores between schools or pupils.

Table 2 A description of the schools classified into three noise exposure bands low, moderate and high aircraft noise exposed schools in terms of school borough, type of school, % eligible for a free school meal, % statemented as having a special need, % English as a second language

Characteristic Total=123	Noise Low n=58	Moderate n=47	High n=18
Borough			
Hillingdon	83 (n=48)	4 (n=2)	6 (n=1)
Hounslow	0 (n=0)	62 (n=29)	89 (n=16)
Windsor and Maidenhead	17 (n=10)	34 (n=16)	6 (n=1)
Type of school			
Government	60 (n=35)	70 (n=33)	83 (n=15)
Church	28 (n=16)	30 (n=14)	17 (n=3)
Grant maintained	12 (n=7)	0 (n=0)	0 (n=0)
Eligible for a free school meal in 1997	14	23	28
Statmented as having a special need in 1997	1.9	1.5	1.4
English as a second language in 1997	12	15	35

Low noise exposure=<57 dBA Leq (16 hr); Moderate noise exposure=57>63 dBA Leq (16 hr); high noise exposure=63>72 dBA Leq (16 hr).

For example, if including the percentage eligible for free school meals in the model results in a reduction in the unexplained variation at the school level, this indicates that deprivation accounts for some of the between school variation. Statistical significance is tested by comparing the goodness of fit of two alternative models and testing whether the improvement in fit is statistically significant. This method has been used to produce the significance levels given in the text for the statistically significant associations.

To explore whether the effects of noise on performance are a dose-response function, a linear term for noise exposure was included in the multilevel models. These analyses will assess if the impairments in school performance are associated with a monotonic increase in noise exposure.

Results from two models are presented. The first model (Model 1) estimates the association between noise and SATs scores after adjustment for sex, year of testing, and type of school. The second model (Model 2) adjusts additionally for the percentage of pupils eligible for a free school meal at the school level, a measure of social deprivation.

As was planned, preliminary analyses were conducted including "English as a second language" and "percentage of children statemented with special needs" in the fully adjusted model. These analyses revealed that adjustment for these factors were no longer significant after adjustment for percentage eligible for free school meals. Thus, they were not included in the final model because they did not add any further information. Date of birth was only available for the 1997 data. An additional analysis was carried out restricted to 1997 data to confirm that adjustment for age of pupil did not change the results.

RESULTS

1 School sample

Table 2 describes the schools by noise exposure. The majority of the schools exposed to high levels of aircraft noise (n=16) were situated in Hounslow; low levels of aircraft noise in Hillingdon (n=48) and moderate levels of aircraft noise in Hounslow(n=29). There were less government schools (60%) and more church schools (28%) in the sample of low noise exposed schools than the high and moderate noise exposed schools. Schools exposed to low levels of aircraft noise had less pupils eligible for free school meals (14%) than children in moderate (23%) or high (28%) aircraft noise exposed schools. Percentage of children statemented as having a special need did not vary much by school noise exposure. Schools exposed to high levels of aircraft noise had more children with English as a second language (35%) compared with children in moderate (15%) or low aircraft (12%) noise exposed schools.

2 Dose-response aircraft noise effects on school performance: adjusted and unadjusted multilevel models

English

Table 3 gives unadjusted means for performance in English. The trend across these unadjusted raw mean scores is statistically significant (noise coefficient = –0.70 standard error = 0.34). After adjustment for type of school, year of testing and sex of child, the association between noise level and performance in English is no longer significant (table 4, Model 1). This remains non-significant after further adjustment for eligibility for free school meals (table 4, Model 2)

Table 3 The unadjusted raw performance means and standard deviations for SATs scores for English, spelling, handwriting, creative writing, reading, mathematics, and science across the noise contours (dBALeq)

Performance indicator Mean SD	Noise contour band <54	54>57	57>60	60>63	63>66	66>69	69>72
English	60.4 (16)	56.2 (16)	59.2 (16.6)	56.2 (16.4)	60.3 (15.8)	55.9 (15)	53.9 (16.4)
Spelling	6.6 (2.7)	6.4 (2.8)	6.4 (2.8)	6.6 (2.7)	6.8 (2.7)	6.7 (2.6)	5.4 (2.6)
Handwriting	3.8 (0.9)	3.4 (0.9)	3.6 (0.9)	3.6 (0.8)	3.9 (0.9)	3.5 (0.9)	3.8 (0.8)
Creative writing	21.6 (4.9)	20.9 (5.2)	21.3 (5.0)	20.2 (5.2)	22.0 (4.7)	20.5 (4.8)	21.5 (5.7)
Reading	28.5 (9.8)	26.0 (9.5)	27.9 (10.3)	26.5 (9.8)	27.7 (10.0)	25.2 (9.4)	23.5 (10.1)
Mathematics	46.4 (15.4)	43.8 (13.7)	44.8 (15.7)	45.0 (14.9)	43.8 (15.4)	43.1 (15.3)	35.6 (13.6)
Science	49 (12.7)	46.4 (11.2)	48.9 (13.1)	48.6 (13.6)	48.6 (13.1)	46.5 (13.6)	42.7 (12.3)

The test for a noise effect for performance unadjusted for any factor noise coefficents and standard errors are as follows: English –0.7 (0.34); spelling –0.04 (0.05); handwriting –0.02 (0.02); creative writing –0.13 (0.10); reading –0.52 (0.21); mathematics –0.81 (0.32); science –0.46 (0.31). The effect is statistically significant for English, reading and mathematics and not for any of the other performance outcomes.

Table 4 The multilevel models for the performance outcomes of English, spelling, handwriting, writing, reading, mathematics, and science unadjusted and fully adjusted: estimates and (standard errors)

Fixed coefficients	English Model 1 n=10998	English Model 2 n=10998	Spelling Model 1 n=10957	Spelling Model 2 n=10957	Handwriting Model 1 n=10957	Handwriting Model 2 n=10957	Creative writing Model 1 n=10957	Creative writing Model 2 N=10957	Reading Model 1 n=10957	Reading Model 2 N=10957	Maths Model 1 n=11105	Maths Model 2 N=11105	Science Model 1 n=11163	Science Model 2 n=11163
Intercept	56.88 (1.07)	60.09 (1.00)	6.07 (0.15)	6.53 (0.15)	3.6 (0.06)	3.68 (0.07)	19.72 (0.3)	20.16 (0.35)	27.64 (0.6)	29.8 (0.58)	45.29 (1.03)	48.09 (1.02)	49 (1.0)	50.06 (1.07)
Noise level	−0.54 (0.31)	0.12 (0.27)	−0.02 (0.04)	0.07 (0.04)	−0.01 (0.02)	0.01 (0.02)	−0.09 (0.10)	0.01 (0.10)	−0.42 (0.19)*	0.03 (0.16)	−0.73 (0.30)†	−0.15 (0.28)	−0.44 (0.30)	−0.22 (0.30)
Sex (F v M)	5.84 (0.28)	5.86 (0.28)	0.7 (0.05)	0.75 (0.05)	0.31 (0.02)	0.31 (0.02)	2.0 (0.08)	2.01 (0.09)	2.81 (0.18)	2.82 (0.18)	−1.28 (0.27)	−1.27 (0.27)	0.03 (0.22)	0.04 (0.23)
Year (97 v 96)	−1.58 (0.28)	−1.72 (0.28)	−0.09 (0.04)	−0.11 (0.05)	−0.15 (0.02)	−0.16 (0.02)	0.99 (0.09)	0.97 (0.09)	−2.43 (0.18)	−2.53 (0.18)	2.49 (0.27)	2.37 (0.27)	−0.11 (0.23)	−0.16 (0.23)
Church v Gov	6.77 (1.15)	4.44 (0.99)	0.8 (0.16)	0.49 (0.15)	0.13 (0.07)	0.07 (0.07)	1.6 (0.36)	1.27 (0.36)	4.17 (0.68)	2.58 (0.58)	5.55 (1.11)	3.49 (1.02)	4.21 (1.08)	3.43 (1.08)
GM v Gov	1.24 (2.19)	0.61 (1.76)	0.06 (0.31)	−0.03 (0.27)	0.04 (0.12)	0.03 (0.12)	0.4 (0.68)	0.31 (0.63)	0.7 (1.3)	0.25 (1.02)	−0.67 (2.11)	−1.27 (1.81)	−1.97 (2.08)	−2.20 (1.96)
% eligfsm	–	−0.22 (0.03)	–	−0.03 (0.01)	–	−0.01 (0.01)	–	−0.03 (0.01)	–	−0.15 (0.02)	–	−0.19 (0.03)	–	−0.07 (0.03)
Random parameters														
Level 2: (school)	26.95 (3.84)	16.47 (2.48)	0.52 (0.08)	0.36 (0.06)	0.09 (0.01)	0.08 (0.01)	2.63 (0.37)	2.23 (0.32)	9.54 (1.37)	5.42 (0.84)	25.10 (3.57)	17.74 (2.6)	24.94 (3.44)	21.87 (3.04)
Level 1: (pupil)	218.2 (2.96)	218.7 (2.96)	6.6 (0.09)	6.6 (0.1)	0.6 (0.01)	0.6 (0.01)	20.4 (0.28)	20.4 (0.28)	83.6 (1.2)	83.8 (1.14)	203.6 (2.75)	203.9 (2.8)	140.9 (1.90)	141 (1.90)

*p=0.025, †p=0.014. Model 1: adjusted for sex, year of testing and type of school. Model 2: additionally adjusted for eligibility for free school meals.

Reading, spelling, handwriting, and writing

A closer analysis of the subscales of the four English tests shows that aircraft noise exposure affects performance on the reading test more than the other subtests: spelling, handwriting, creative writing (see table 3 for raw means and table 4 for modelling). As noise levels increase by contour band, performance in reading drops by 0.42 of a mark (p=0.025). After adjustment for percentage of pupils eligible for free school meals the noise effect is lost on the reading test.

Mathematics

Noise level is significantly related to mathematical performance (see table 3 for raw means and table 4 for modelling). As noise levels increase by contour band, performance drops by 0.73 of a mark (p=0.014). After adjustment for percentage of pupils eligible for free school meals the association is no longer statistically significant.

Science

The results for the raw means and adjusted models show that noise level is not associated with performance in Science (see table 3 for raw means and table 4 for modelling).

DISCUSSION

There were four main findings in this study. Firstly, as predicted, chronic exposure to aircraft noise was significantly related to poorer reading performance and was not associated with the other English performance outcomes, spelling, writing, and handwriting. Secondly, chronic exposure to aircraft noise at school was significantly related to poorer performance on a nationally standardised test of mathematics after adjustment for school type. Thirdly, after adjustment for the average socioeconomic status of the school intake, measured by the percentage eligible for a free school meal, the association between high noise exposure and poorer performance on the SATs tests is reduced and is no longer statistically significant. Taken together these results suggest that chronic exposure to aircraft noise is associated with school performance in reading and mathematics in a dose-response function, but that this association is influenced by socioeconomic factors.

The divergent performance across the different subtests of the English test supports previous research on noise related reading deficits.[1–7 12 13 19] The specific effect on reading provides empirical support for the theory that tasks with a high component of language comprehension dependent on listening and comprehension are more affected by noise exposure than other tasks, which are less language-based such as spelling, handwriting, and writing. These divergent results across the English subtests, provide only suggestive evidence that chronic exposure to aircraft noise affects language-based tasks more that other cognitive tasks, because of the significant noise effect on mathematical performance (a control outcome) and because after adjustment for socioeconomic factors (measured as the free school meal ratio), the association between noise and reading was lost.

The pattern of results across the performance outcomes showing that the strongest association between noise and performance before adjustment for socioeconomic status was for mathematics compared with reading, was unexpected. Six previous studies [1 2 6–8 19 21] examining the effects of noise exposure on mathematical ability have yielded equivocal results: two studies found an effect[1 21] and the other four found no effect.[2 6 8 20] There is no current theory to explain why noise exposure might affect mathematical ability because it has been assumed that high levels of noise exposure do not have an effect on mathematics. However, mathematics can be likened to a new language with new terms, concepts, symbols, and constructions of sequences of numbers that could be analogous to sentences. Viewed in this way, one might expect the effects of noise on mathematics to occur through similar mechanisms to the effects on reading. On the other hand, it could be that that noise exposure influences both reading and mathematics through different mechanisms. It is possible to speculate that an effect of noise on mathematical ability might be attributable to another mechanism apart from the psycholinguistic mechanisms thought to underlie the previously found reading and memory deficits. The results from this study, which indicate noise exposure is related to impairments in mathematics, compel researchers to consider that a wider range of performance outcomes are affected by chronic exposure to aircraft noise.

The mathematics and reading results discussed above have been adjusted for the influence of school type and the clustering of children within schools has been allowed for by using the multilevel modelling. It is important to note that this SATs study using a sample of 123 schools and approximately 11 000 individual scores per outcome, provides evidence for the first time that noise is found to affect reading and mathematical performance after adjustments have been made for school level factors. Future studies need to sample a sufficient enough number of schools so that both school level and individual level factors can be adjusted for accordingly with multilevel modelling statistical techniques.

The association between high noise exposure and poorer performance on the SATs tests is significantly reduced and is no longer statistically significant after adjustment for socioeconomic status, measured by free school meal ratio at the school level. There are at least two possible interpretations of this effect of socioeconomic status on SATs performance. The obvious interpretation is that socioeconomic status confounds the association between noise and school performance, and explains the noise effect. This implies that the effects of noise exposure could be a marker for a socioeconomic effect on performance.

However, statistical treatment of social deprivation as a confounding factor, may not adequately account for the pre-existing association between these factors. This relation can be summarised as follows: poorer quality schools are more common in socially deprived areas, which are also more likely to be exposed to high levels of aircraft noise. Social deprivation, school quality, and noise exposure are all known to adversely influence school performance. Adjustment for social deprivation might be over adjustment, because this statistical method does not take into account the broader ecological context in which environmental stressors, such as noise exposure, exist.[10] This is because other research has suggested that deprivation has separate effects at both the school and individual level. That is, being at a school in a deprived area can influence performance irrespective of individual deprivation level. This is called a context effect. In this case, noise exposure, as an aspect of the local environment, may be a mediating factor in the association of social deprivation and performance.

In the fully adjusted multilevel models it is difficult to draw strong conclusions regarding the interrelation of noise exposure, school performance, and socioeconomic status. It cannot be concluded that noise exposure has no effect whatsoever on reading and mathematics because of the effect found in the unadjusted models and evidence of previous research.[1–7 12 13 19 22] None the less, on the other hand, to conclude that the fully adjusted models constitute a gross over adjustment that masks a noise effect, may also not be accurate. These SATs results suggest that it is possible that the noise related performance effects are not independent from the effects of social disadvantage on performance. That is to say, that both noise exposure and social class are interrelated and they combine together to influence performance. The nature of the pathways between social class, noise and performance are unknown and need further theoretical consideration and empirical examination.

This study provides better evidence than previous studies because of its methodological and analytical innovations and design strengths. The multilevel modelling statistical method is more appropriate than any other method of analysis used in previous studies to examine individual level school performance in relation to aircraft noise exposure adjusting for school level factors. The design of the study using control outcomes (science and mathematics) could be useful in future research for interpreting whether a third unmeasured factor is confounding the relation between school performance and noise exposure. This design allowed previous theory to be empirically examined because divergent predictions about the association between noise exposure and performance could be generated and tested. The SATs data are nationally standardised and normed, so they are reliable, and the multilevel modelling analyses are the most valid analyses considering that the data are clustered.

There are several limitations of this study. It could be argued that the proposed study confounds chronic and acute effects because it relies on archival records of achievement tests, where indoor and outdoor noise exposure at the time of testing is unknown. However, results from previous research in controlled testing environments[8 12 22] strongly suggest that impairments in school achievement are caused by chronic and not acute exposure. It must be noted that it is contentious how reliably these CAA contours estimate actual exposure level because they are formulated on average aircraft noise exposure over a 16 hour period and are calculated during the summer including part of the time when schools are not open.[23] It would have been more sensitive to supplement the school level adjustment for socioeconomic status with an adjustment for deprivation at the individual level and link it directly to performance. This is because other research has suggested that deprivation has separate effects at both the school and individual level. That is, being at a school in a deprived area can influence performance irrespective of individual deprivation level, a context effect.[24]

Taken together, these results suggest that chronic exposure to aircraft noise is associated with school performance in reading and mathematics in a dose-response function, but that this association is influenced by socioeconomic factors. These results suggest that it is still an open issue as to whether chronic aircraft noise exposure effects language-based tasks exclusively because aircraft noise had the strongest effect on mathematical performance. The models fully adjusted for socioeconomic status provide limited information about the interrelation between noise exposure, school performance, and socioeconomic status. The results from both the unadjusted and fully adjusted models suggest that both noise exposure and socioeconomic status are interrelated and combine to influence performance. As a priority, future research ought to address the main question that these results beg: to understand to what extent does noise exposure adversely effect child school performance over and above the influence of socioeconomic status on performance? Future research

Key points

- Previous research suggests that environmental noise exposure at school has been associated with poorer school performance.
- The aim of this study is to examine the effects of exposure to aircraft noise on children's school performance.
- National Standard Scores (SATs) from 11 000 children in 123 primary schools around Heathrow Airport in London were used.
- The primary schools were geocoded into five aircraft noise exposure bands.
- The results suggest that chronic exposure to aircraft noise is associated with school performance in reading and mathematics in a dose-response function but this association is influenced by socioeconomic factors.

should be conducted concurrently with detailed theoretical consideration of the nature of the pathways between socioeconomic status, noise exposure, and performance.

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Contributors

All the listed authors have contributed significantly to the manuscript and consent to have their names on the manuscript. Mary Haines was the primary author of all drafts of the manuscript, conducted the data collection and worked with the other authors to design the study and interpret the data. Stephen Stansfeld co-designed the study, interpreted the data and revised the final versions. Jenny Head co-designed the study, conducted the statistical analyses, interpreted the data and revised the content of the final versions. Soames Job co-designed the study, interpreted the data and revised the content of the final versions. All authors certify that they take public responsibility for the content of this study and will provide any relevant data upon request.

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