The long-term effects of aircraft noise exposure on children's cognition: findings from the UK RANCH follow-up study

C. Clark[1], J. Head[2], S.A. Stansfeld[1]

[1] Centre for Psychiatry, Barts & the London School of Medicine, Queen Mary, University of London, London, EC1M 6BQ, UK, c.clark@qmul.ac.uk, s.a.stansfeld@qmul.ac.uk

[2] Department of Epidemiology & Public Health, University College London, 1-19 Torrington Place, London, WC1E 7HB, UK, j.head@ucl.ac.uk

INTRODUCTION

Exposure to transport noise is an increasing and prominent feature of the urban environment. The RANCH project (Road Traffic Noise and Aircraft Noise Exposure and Children's Cognition and Health), the largest study of noise and children's cognition undertaken to date, examined the effects of aircraft noise and road traffic noise exposure at primary school on the cognitive performance of 2,844 9-10 year old children attending 89 schools around Heathrow (London), Schiphol (Amsterdam), and Barajas (Madrid) airports. The study found linear exposure-effect relationships between aircraft noise exposure at school and children's reading comprehension and recognition memory (Clark et al. 2006; Stansfeld et al. 2005).

Whilst previous studies had demonstrated effects of chronic aircraft noise exposure on primary school children's reading comprehension and long-term memory, comparing children with high noise exposure with those with low noise exposure (Haines et al. 2001a; Hygge et al. 2002), the RANCH study was the first to examine exposure-effect relations and to compare the effect of noise exposure on children's cognition across countries. The development of cognitive abilities such as reading are important not only in terms of educational achievement but also for subsequent life chances and adult health (Kuh & Ben-Shlomo 2004). To understand the causal pathways between noise exposure and cognition, and design preventive interventions, there is a need to study these associations longitudinally. However, few longitudinal studies have examined the effects of persistent exposure throughout the child's education: a study over only a one-year period found that deficits in reading comprehension persisted and that children did not adapt to their noise exposure (Haines et al. 2001b). Studies of noise abatement suggest that a reduction of noise exposure eliminates previously observed reading deficits (Bronzaft 1981; Hygge et al. 2002) but studies of the long-term consequences of noise exposure during primary school for later cognitive development have not been conducted.

This study followed the UK sample of the RANCH cohort to examine the long-term effects of aircraft noise exposure at primary school on children's reading comprehension. This paper examines whether children who attend aircraft noise exposed primary schools experience impaired reading comprehension during secondary school, compared with peers who were not exposed to aircraft noise at primary school. The paper also examines associations between aircraft noise exposure at secondary school and reading comprehension.

METHOD

Design

A quantitative longitudinal epidemiological follow-up of the UK RANCH cohort, six years after the initial RANCH baseline study was carried out. This was an exposure-effect study with participants drawn from across a range of aircraft noise exposures at school from low to high at both baseline and follow-up.

Pilot study

Tracing the cohort: the cohort was originally selected, on the basis of noise exposure at primary school, from the London Boroughs of Hounslow, Hillingdon, and Slough. We traced the cohort members using home address provided at baseline, through primary and secondary schools, and Local Education Authorities (LEAs). The secondary school attended for 77.8 % [N=1,054] of the sample was identified: no secondary school could be identified for 18.5 % [N=251] of the sample and a further 3.7 % [N=50] declined to take part in the follow-up study during the pilot study phase. Whilst the baseline study was conducted in 29 schools in 3 boroughs, the sample was traced to 80 secondary schools in 13 boroughs [excluding those schools outside of West London], with the majority remaining in Hounslow [31.2 %], Hillingdon [16.2 %], and Slough [18.6 %], or in the adjacent boroughs of Richmond [3.5 %], Surrey [3.0 %] and Windsor & Maidenhead [2.4 %]. It was not feasible to follow-up the sample in other boroughs where there were less than 12 cohort members per LEA or in boroughs outside West London [2.9 %]. Thus, 1015 cohort members from 58 secondary schools could participate in the follow-up study (74.9 % of the original sample).

Pilot of test materials: At baseline a range of cognitive abilities were measured, including reading comprehension, long-term memory, and working memory during a test session which lasted for one morning. At follow-up we had access to the participants for one 45-minute class and planned to measure reading comprehension, which had shown the strongest association with aircraft noise exposure at baseline. At baseline, reading comprehension was measured using the Suffolk Reading Scale 2, Level 2: a 30 minute test of 76 items suitable for 8-11 year olds (Hagley 2002): a test suitable for older children was required for the follow-up study. A pilot study of 89 14-15 year olds attending 3 secondary schools in Tower Hamlets conducted in early 2007 compared two reading comprehension tests: the Suffolk Reading Scale 2, Level 3 (Hagley 2002) and the Access Reading Test (McCarty & Crumpler 2006), and piloted a child questionnaire, adapted from the baseline child and parent questionnaires, assessing socio-demographic factors. Between and within group analyses of the reading comprehension tests revealed that participants were more likely to complete the Suffolk test compared with the Access test. Scale reliability was also higher for the Suffolk test (alpha=0.90 versus 0.83). The Suffolk test was selected for use in the follow-up given the stronger descriptive data from the pilot study, as well as the comparability afforded with the baseline measure of reading comprehension.

Measures

Noise Exposure Assessment: At both baseline and follow-up aircraft noise estimates were based on 16-hour outdoor L_{Aeq} contours available nationally from the Civil Aviation Authority. At baseline these data were from July to September 1999; at follow up

these data were from July to September 2007. These contours were used to estimate aircraft noise exposure at school for each participant, based upon postcode data. At baseline acute noise measurements during testing were taken inside and outside the classroom: however, analyses revealed that acute noise had no effect on the observed association between aircraft noise and reading comprehension: acute noise was therefore not measured during the follow-up study. Aircraft noise exposure at baseline and follow-up are analysed as continuous variables.

Reading Comprehension: was measured using the Suffolk Reading Scale 2 Level 2 at baseline and Level 3 at follow-up (Hagley 2002). These are established, nationally standardised tests. The Level 2 test is a 30 minute test of 86 items suitable for 8-11 year olds; the Level 3 test is a 30 minute test of 76 items suitable for 11-15yrs 4m[1]. The test contains multi-choice questions with 5 potential answers. The questions become progressively harder as the child works through the test. The test, introduced as a 'complete the sentence activity', was conducted in silence, in exam-like conditions, and was timed out after 30 minutes. The test produces standardised scores using national norms and was converted to Z-scores for consistency with the baseline reading scale data.

Potential Confounding Factors: Data was available from child and parent questionnaires administered at baseline which assessed socioeconomic status, parental and child health, and other demographic factors. At baseline the schools were matched in terms of sociodemographic data, which was not possible at follow-up. Baseline confounding factors included in the analyses include the child's age and gender, parental employment, crowding in the home, home ownership, mother's educational attainment, parental support for school work, long-standing illness of the child, main language spoken at home, and classroom glazing (Stansfeld et al. 2005).

Procedure

1,015 participants who had taken part in the initial baseline RANCH study in primary school, who now attended secondary schools in Hillingdon, Hounslow, Slough, Windsor & Maidenhead, Surrey, and Richmond, were invited to take part in the follow-up study. The participants were all in school year 11, aged 15-16 years. Data was collected from March to May 2008, during a 45 minute lesson. Written consent was obtained from the head teacher. Parents and participants received an information letter about the study one week prior to data collection; passive consent was obtained from parents who could opt their child out of the study if they wished. Written consent was obtained from the participant on the day of the study, after giving a further verbal explanation of the study and an opportunity to answer questions. Ethical approval for this study was obtained from the Queen Mary Research Ethics Committee.

Statistical analysis

Initial analyses compared the characteristics of the cohort members who took part with those who did not take part in the follow-up to ascertain the representativeness

[1] At the time of the study, no standardised reading test in the UK was suitable for children 16 years or older. Our sample included children aged 15 and 16 years of age. We discussed this with the publishers of the Suffolk Reading Scale 2, NFER-NELSON, who foresaw no additional problems of using the test with a sample up to 16yrs 6m (Personal Communication).

of the achieved follow-up sample. Then the baseline model of aircraft noise exposure at primary school on reading comprehension was re-run on the follow up-sample, to see if it could be replicated in this sub-sample. Descriptive statistics exploring patterns of aircraft noise at primary and secondary school for the sample were examined. Multilevel modelling linear regression analyses examining the effect of primary school and secondary school aircraft noise exposure on follow-up reading comprehension were carried out. These models take into account the hierarchical nature of the data, of pupils being nested within schools and adjusted for confounding factors measured at baseline, which assessed socioeconomic status, child health, and other demographic factors.

RESULTS

Response rate and attrition

461 participants [45.4 %] of the target sample took part in the follow-up study: 201 males [43.6 %] and 260 females [56.4 %]. The age of the participants ranged from 15yrs 4m to 16yrs 8m, with an average age of 15yrs 7m.

Of those who did not take part in the study, it was not feasible to include 39 [3.8 %] participants who attended schools with fewer than 5 participants or 8 [0.8 %] participants who attended schools for children with special needs. The lack of consent for the study to take place in their school by head teachers resulted in 190 [18.7 %] participants not taking part in the study: very few parents or participants opted out of the study [N = 28, 2.8 %]. In total 11 out of the 58 schools refused consent for data to be collected in their school. 122 [12.0 %] participants had left the school in the year since the tracing work had been completed and could not be retraced: a further 167 [16.5 %] were unavailable for testing on the day due to absence from school or other school activities. This covered a broad range of reasons from other school activities, including GCSE exams, through to having been excluded from school.

In order to assess the impact of our response rate on the representativeness of the sample several analyses were carried out comparing the baseline characteristics of the cohort members who took part at follow-up [N-461] with those cohort members who did not take part at follow-up [N=554]. These analyses suggested no differential non-response by baseline exposure to noise or sociodemographic characteristics.

Patterns of aircraft noise exposure at school at baseline and follow-up

Patterns of baseline and follow-up aircraft noise exposure are presented in Table 1 for the 461 cohort members who took part in the follow-up study. At baseline, aircraft noise range from 34 dBA to 68 dBA: the mean exposure was 54 dBA. At follow-up, aircraft noise exposure ranged from <50 dBA to 65.4 dBA: the mean exposure was 54 dBA. Overall, nearly half of the participants (N=217, 47 %) were attending secondary schools with a similar noise exposure level to their primary school: 51.4 % for <51 dBA, 60.5 % for 51-56.9 dBA and 64.4 % for 57-62.9 dBA. For those exposed to >63 dBA at baseline, most were attending secondary schools with exposure between 57-62.9 dBA (84.2 %): only 5 % remained in schools with the highest exposure (>63 dBA). The data indicate that in our sample, some cohort members remain exposed to high levels of aircraft noise at secondary school, whilst some have moved from noise exposed to quieter schools, and some have moved from quieter schools to noisier schools at follow-up.

Table 1: Noise exposure at primary and secondary schools in Hounslow, Hillingdon, Slough & Windsor, Surrey, Berkshire, and Richmond for the cohort who participated in the follow-up (N=461)

Aircraft noise exposure at primary school ↓	Aircraft noise exposure at secondary school ↓			
	<51 dBA N [%]	51-56.9 dBA N [%]	57-62.9 dBA N [%]	>63 dBA N [%]
<51 dBA	75 [51.4 %]	38 [26.0 %]	33 [22.6 %]	0 [0.0 %]
51-56.9 dBA	20 [16.8 %]	72 [60.5 %]	27 [22.7 %]	0 [0.0 %]
57-62.9 dBA	8 [7.9 %]	27 [26.7 %]	65 [64.4 %]	1 [1.0 %]
>63 dBA	4 [4.2 %]	6 [6.3 %]	80 [84.2 %]	5 [5.3 %]
[%]=row %.				

Effects of aircraft noise at school on reading comprehension

Initially, the baseline model of aircraft noise exposure at primary school on reading comprehension was re-run on the follow-up sub-sample (N = 461) to assess whether the original RANCH reading findings (Clark et al. 2006; Stansfeld et al. 2005) could be replicated in the sub-sample participating at follow-up. Multilevel modelling analyses (Table 2) indicated that the effect size for the UK sample in the original sample was replicated in our sub-sample. This is suggestive that the achieved sample is representative of the UK baseline cohort.

Of the sample, 20 % had reported both parents as being unemployed at baseline; 40 % did not own their home; 22 % had reported a crowded home; 27 % of the sample had a long-standing illness; and 20 % had reported not speaking English at home; 57 % of the follow-up sample was female. Table 3 (model 1) shows the multilevel model analyses for the effect of aircraft noise at primary school on secondary school reading comprehension, adjusted for baseline socioeconomic and demographic factors. The model shows that for every 1 dB increase in primary school noise exposure, performance on the reading comprehension test decreases by -0.007: however, this effect was not significant, indicating that children who attended noise exposed primary schools did not have significantly poorer reading comprehension compared with children who attended non-noise exposed primary schools.

Table 2: The effect size of aircraft noise at primary school on reading comprehension at primary school for each county and for the UK sub-sample who took part in the follow-up study

	B†	SE	Confidence interval (95 %)	p-value from χ^2
Original findings at baseline				
Pooled estimate	-0.008	0.003	-0.014 to -0.002	0.009
UK	-0.009	0.005	-0.019 to 0.001	
NL	-0.006	0.007	-0.020 to 0.008	
Spain	-0.006	0.005	-0.016 to 0.004	
Original finding at baseline for the follow-up sample				
UK	-0.009	0.005	-0.019 to 0.001	0.051
† indicates change in reading z-score per 1 dB increase in noise exposure at primary school				

Table 3 (model 2) shows the multilevel model analyses for the effect of aircraft noise at secondary school on secondary school reading comprehension, adjusted for baseline socioeconomic and demographic factors. The models show that for every 1 dB increase in secondary school noise exposure, performance on the reading compre-

hension test decreases by -0.023: however, this effect was not significant, indicating that children who attended noise exposed secondary schools did not have poorer reading comprehension compared with children who attended non-noise exposed secondary schools.

Table 3: The multilevel model parameter estimates for aircraft noise at primary school and secondary school on reading comprehension at secondary school for the UK follow-up sample (N=342)

	Model 1 Aircraft noise at primary school			Model 2 Aircraft noise at secondary school		
Fixed coefficients	B	95 % CI	p-value	B	95 % CI	p-value
Aircraft noise at primary school	-0.007	-0.02 to 0.004	0.22	-	-	-
Aircraft noise at secondary school	-	-	-	-0.023	-0.060 to 0.012	0.200
Age	-0.00002	-0.0003 to 0.0002	0.87	0.0000001	-0.0002 to 0.00027	0.952
Female	-0.30	-0.51 to -0.90	0.005	-0.31	0.52 to -0.10	0.003
Employed	-0.05	-0.34 to 0.24	0.73	-0.08	-0.36 to 0.20	0.578
Crowded	-0.23	-0.49 to 0.03	0.08	-0.24	-0.50 to 0.01	0.063
Home owner	0.32	0.085 to 0.55	0.007	0.27	0.05 to 0.50	0.018
Mother's education	-0.60	-0.98 to -0.23	0.002	-0.58	-0.94 to -0.21	0.002
Long standing illness	-0.02	-0.25 to 0.21	0.85	0.01	-0.21 to 0.23	0.923
Speak main language at home	0.11	-0.16 to 0.39	0.42	0.16	-0.12 to 0.45	0.276
Parental support	0.08	0.03 to 0.14	0.001	0.78	0.03 to 0.13	0.003
Classroom glazing	0.26	-0.97 to 0.15	0.68	-	-	-
Road noise at primary school	0.007	-0.008 to 0.022	0.395	-	-	-
Random parameters	B	SE		B	SE	
Level 2: Primary school	0.90	0.07		0.81	0.06	
Level 1: Pupil	0.014	0.03		0.10	0.05	
B = change in outcome score associated with 1 db change in noise						

CONCLUSION

This is the first study to examine the long-term effects of aircraft noise exposure at primary school on children's later cognitive performance. This study compared the performance on a standardised reading comprehension task for children aged 15-16 years of age, who attended primary and secondary schools exposed to varying levels of aircraft noise around London Heathrow airport. This study found that children who attended aircraft noise exposed primary schools did not have significantly poorer reading comprehension at secondary school compared with children who were not exposed to aircraft noise at primary school. Similarly, children who attended aircraft noise exposed secondary schools did not have significantly poorer reading comprehension compared with children who were not exposed to aircraft noise at secondary school.

These conclusions however, need to be considered in the light of some of the limitations of this study. The achieved sample size for the follow-up of the RANCH study was fairly small with 342 participants having complete data from baseline and follow-up. The sample size could potentially have influenced the findings in several ways. Firstly, the coefficients for the effect of aircraft noise at primary and secondary school

are both negative and sizeable, but are not significant. This suggests that whilst aircraft noise was associated with impaired performance on the reading comprehension test the achieved sample may lack the power to detect a statistically significant difference. This argument is further supported by the similarity in the coefficient for primary school noise exposure and its effect on reading comprehension in secondary school (-0.007) with the earlier finding of an effect on reading comprehension in primary school (-0.009) (Stansfeld et al. 2005). Secondly, many previous small-scale studies of noise effects on children's cognition have failed to demonstrate effects, whilst larger studies, such as the RANCH study, have demonstrated effects. This suggests that smaller scale samples in this field are more likely to result in type II errors, which may be the case in our follow-up study. Future studies need to ensure a larger sample is followed over-time, in order to test whether effects of noise exposure in primary school, on secondary school cognitive performance can be demonstrated.

One considerable limitation for longitudinal studies is attrition and we have lost over half of the original UK RANCH sample from our follow-up sample as we were not able to trace them from primary school into secondary school; because schools refused to take part in the follow-up; and because pupils were often absent from school or involved in other school activities on the day of data collection. We have compared whether the follow-up sample is representative of the UK baseline cohort in two ways. Analyses comparing the baseline characteristics of cohort members who took part in the follow-up with those who did not revealed no differential non-response by baseline noise exposure at primary school or by sociodemographic characteristics. Further, we were able to replicate the original RANCH findings of an association between aircraft noise at primary school and reading comprehension in the sub-sample who took part in the follow-up. Together, these analyses suggest that the achieved sample is largely representative of the UK baseline cohort, however, given the level of attrition in the sample, we should consider the results as indicative rather than definitive. Also, in terms of the secondary schools sampled, it should be remembered that the secondary schools may not be representative of the population or of aircraft noise exposure, as the sample was not selected by secondary school noise exposure, per se.

Further limitations of the study include a lack of information about exposure to road traffic noise and air pollution at secondary school, about aircraft noise exposure at the child's home at follow-up, and about internal acoustic conditions in the classroom and acute noise exposure during testing. The study is also restricted to one cohort in only one country, so the results may be country and cohort specific. However, to our knowledge, this is the first study to prospectively examine the effect of aircraft noise exposure in primary school and its effect on cognitive performance in secondary school and there are few large scale studies of noise effects on children's cognition which could be followed-up in this way. Other strengths of this study include data on a comprehensive and wide-range of individual-level confounding factors as well as the use of multilevel modelling which enabled the effect of both school-level and individual-level variables to be examined.

Overall, the findings of the current study are mixed; whilst there was no significant effect of aircraft noise exposure at primary school or secondary school on reading comprehension assessed at secondary school, the results do indicate a trend for noise exposure on both occasions to be associated with poorer performance on

reading comprehension. These findings, taken with the evidence from the RANCH study for an effect of aircraft noise at primary school on reading comprehension assessed at primary school, raise concerns regarding the effect of chronic aircraft noise exposure at school on children's reading ability. Further, the coefficient for aircraft noise exposure at secondary school was three times larger than the coefficient observed for aircraft noise exposure at primary school. This could reflect a larger influence of contemporaneous secondary school aircraft noise exposure compared with exposure at primary school, but it could be indicative of a larger, cumulative effect of noise exposure at school on the child's cognition, observable by the end of the child's school career. Such an effect would be supported by previous evidence: a study over only a one-year period found that deficits in reading comprehension persisted and that children did not adapt to their noise exposure (Haines et al. 2001b). To understand the causal pathways between noise exposure and cognition, and to design preventive interventions, there is a need for further longitudinal evidence of the effects of noise exposure throughout the child's education.

Further analyses of the RANCH follow-up study data will examine whether some children are more susceptible to long-term effects of noise on reading comprehension. The association of noise exposure at primary and secondary school on educational achievement, as measured by national exam data for the participants, will also be examined and may yield less equivocal findings. As well as the need for further longitudinal studies examining the long-term consequences of noise exposure during primary school for later cognitive development, future research should also examine the interaction between external noise exposure and internal classroom acoustics; assess the potential protective effect of classroom insulation to reduce noise effects on cognition; and further assess exposure-effect relationships between primary and secondary school noise exposure and cognition.

The results of this project have implications for noise policy within the UK and the results have relevance to European, national and local authorities involved in public health, transport planning, and land-use planning. This study is the first to utilise prospective data to assess the long-term consequences of noise exposure during primary school for later cognitive development but the findings are limited by the scale of the follow-up study. In terms of policy implications, taken as a whole, the RANCH study findings indicate that a chronic environmental stressor – aircraft noise exposure at school – could impair cognitive development in children, specifically reading comprehension. Schools exposed to high levels of aircraft noise are not health educational environments.

REFERENCES

Bronzaft AL (1981). The effect of a noise abatement program on reading ability. J Environ Psychol 1: 215-222.

Clark C, Martin R, van Kempen E et al. (2006). Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension: the RANCH project. Am J Epidemiol 163: 27-37.

Hagley F (2002). The Suffolk Reading Scale 2. NFER-Nelson: Windsor.

Haines MM, Stansfeld SA, Brentnall S et al. (2001a). The West London Schools Study: the effects of chronic aircraft noise exposure on child health. Psychol Med 31: 1385-1396.

Haines MM, Stansfeld SA, Job RF et al. (2001b). A follow-up study of effects of chronic aircraft noise exposure on child stress responses and cognition. Int J Epidemiol 30: 839-845.

Hygge S, Evans GW, Bullinger M (2002). A prospective study of some effects of aircraft noise on cognitive performance in schoolchildren. Psychol Sci 13: 469-474.

Kuh D, Ben-Shlomo Y (2004). A lifecourse approach to chronic disease epidemiology. Oxford: Oxford University Press.

McCarty C, Crumpler M (2006). Access Reading Test. London: Hodder Murray.

Stansfeld SA, Berglund B, Clark C et al. (2005). Aircraft and road traffic noise and children's cognition and health: a cross-national study. Lancet 365: 1942-1949.