



Original Contribution

Does Traffic-related Air Pollution Explain Associations of Aircraft and Road Traffic Noise Exposure on Children's Health and Cognition? A Secondary Analysis of the United Kingdom Sample From the RANCH Project

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The authors examined whether air pollution at school (nitrogen dioxide) is associated with poorer child cognition and health and whether adjustment for air pollution explains or moderates previously observed associations between aircraft and road traffic noise at school and children's cognition in the 2001–2003 Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health (RANCH) project. This secondary analysis of a subsample of the United Kingdom RANCH sample examined 719 children who were 9–10 years of age from 22 schools around London's Heathrow airport for whom air pollution data were available. Data were analyzed using multilevel modeling. Air pollution exposure levels at school were moderate, were not associated with a range of cognitive and health outcomes, and did not account for or moderate associations between noise exposure and cognition. Aircraft noise exposure at school was significantly associated with poorer recognition memory and conceptual recall memory after adjustment for nitrogen dioxide levels. Aircraft noise exposure was also associated with poorer reading comprehension and information recall memory after adjustment for nitrogen dioxide levels. Road traffic noise was not associated with cognition or health before or after adjustment for air pollution. Moderate levels of air pollution do not appear to confound associations of noise on cognition and health, but further studies of higher air pollution levels are needed.

air pollution; child psychology; cognition; environmental pollution; epidemiology; noise; public health; transportation

Abbreviation: RANCH, Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health.

To date, over 20 studies have shown a negative association between environmental noise, such as aircraft or road traffic noise, and children's reading abilities and memories (1–6). Cognitive tasks affected by environmental noise tend to be those involving language and central processing skills, such as reading and memory. Several pathways for associations between chronic noise exposure and children's cognition have been suggested, including teacher and pupil frustration (7), learned helplessness (8), impaired attention (7, 9), increased arousal (10), indiscriminate filtering out of noise (11), and noise annoyance (12).

Road traffic and aircraft noise have also been shown to influence cardiovascular health in adults, and there is some evidence that environmental noise may also influence

children's blood pressure levels (13, 14). Studies have also found associations between environmental noise exposure and children's psychological health (5, 15, 16). However, there has been little examination of the influence of air pollution on the associations observed between environmental noise exposure and children's health and cognition. Children attending schools exposed to high levels of environmental noise may also experience traffic-related air pollution. Although evidence for associations of air pollution with children's respiratory health is robust (17, 18), evidence for associations with children's cognition is equivocal. A study in Boston found that higher levels of black carbon, a marker for traffic particles, were associated with decreased cognitive function in 202 children aged

8–11 years, with associations being found across a range of verbal and nonverbal intelligence and memory assessments (19). However, noise exposure was not measured in that study. A study of Chinese children aged 8–10 years found some significant associations between traffic-related air pollution and neurobehavioral function (20). Conversely, a recent study of 210 Spanish children who were 5 years of age found few significant associations between nitrogen dioxide levels and a range of cognitive and motor abilities (21). Prenatal exposure to air pollution may also be associated with impaired infant mental development (22). Proposed mechanisms for the impact of chronic air pollution on cognition are inflammation or oxidative stress caused by air particles, which influence the central nervous system and lead to neurotoxicity in the brain, potentially influencing brain connectivity (23, 24). Ultrafine particulates may also directly influence the brain by being absorbed in the lungs or via the olfactory nerves (23).

Few studies have examined the impact of coexisting environmental noise and air pollution exposure on children's cognition and health (25). Studies examining the association between the 2 pollutants in general population samples indicated that there were correlations of approximately 0.5–0.6 between nitrogen dioxide and traffic-related noise levels, although local factors, such as traffic and building density, urbanicity, and road layout, influenced the association (26, 27). These studies concluded that there was enough variability between the 2 pollutants to warrant studying the influence of both pollutants using separate measures (26, 27). Little is known about how the 2 pollutants may interact to influence health and cognition (25).

The present article is a secondary analysis of the United Kingdom sample from the Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health (RANCH) project, a cross-sectional epidemiologic study of the associations between aircraft and road traffic noise exposure at school and the health and cognition of 9–10-year-old children in the Netherlands, Spain, and the United Kingdom (2). That study, which to our knowledge is the largest to date, found exposure-effect associations between aircraft noise exposure at school and reading comprehension (3) and recognition memory (2) in the cross-national data. No associations were observed between road traffic noise exposure at school and cognition, with the exception of conceptual recall and information recall, which surprisingly were higher in areas with high road traffic noise in the cross-national data (2). Neither aircraft noise nor road traffic noise affected working memory (2), and there were no significant associations between aircraft noise at school and psychological distress or self-reported health (2). Aircraft noise at school was not associated with systolic and diastolic blood pressure levels in the cross-national data (13); associations were observed for the Dutch sample but not the United Kingdom sample.

The present study had 4 aims. The first was to examine the correlations of aircraft noise exposure and road traffic noise exposure at school with air pollution measured at school for the United Kingdom RANCH sample. The second was to examine whether air pollution at school (nitrogen dioxide) was associated with poorer child cognition

and health outcomes in the United Kingdom RANCH sample. We postulated that air pollution would not be associated with impaired cognitive function and health. The third and fourth aims were to examine whether adjustment for air pollution at school would explain or moderate the previously observed associations of aircraft and road traffic noise exposure at school with children's health and cognition. We postulated that air pollution would not explain or moderate these associations.

MATERIALS AND METHODS

Sampling and design

Children who were 9–10 years of age were selected to participate in this field study based on their noise exposure in schools around London Heathrow airport (2, 3). We conducted a secondary analysis of a subsample of these children for whom air pollution data were available (hereafter referred to as the air pollution subsample). Ethical approval was provided by the East London and the City Local Research Ethics Committee, East Berkshire Local Research Ethics Committee, Hillingdon Local Research Ethics Committee, and the Hounslow District Research Ethics Committee in the United Kingdom; by the Medical Ethics Committee of the Netherlands Organization for Applied Scientific Research, Leiden, the Netherlands; and by the Consejo Superior De Investigaciones Cientificas Bioethical Commission, Madrid, Spain.

Noise exposure assessment

Aircraft noise estimates for the schools were based on 16-hour outdoor L_{Aeq} contours (L_{Aeq} is the "equivalent" average sound level A-weighted to approximate the typical sensitivity of the human ear) provided and validated by the United Kingdom Civil Aviation Authority, which gave the average continuous equivalent sound levels of aircraft noise in an area from 7 AM to 11 PM in July through September of 2000. Estimates of outdoor road traffic noise at the school were based on a combination of proximity to motorways, A roads, and B roads and traffic flow data (28) and were confirmed using noise measurements taken at the facade of the school building (2). In all analyses, aircraft and road traffic noise were entered as continuous variables in dB(A); dB(A) is a measure of sound level in decibels A-weighted to approximate the typical sensitivity of the human ear. See references 2 and 3 for further information about the noise exposure assessment.

Air pollution assessment

Concentrations of nitrogen dioxide ($\mu\text{g}/\text{m}^3$) representing traffic-related air pollution for each school were derived using a combined emission-dispersion and regression modeling approach using the King's College London Emissions Toolkit, which has been validated against known measurements (29). The Emissions Toolkit provides detailed road traffic emissions for over 6,000 major and minor roads in London using hourly link-by-link traffic flow and speed

data to calculate annual average emissions for pollutants from different types of vehicles. Emission estimates were for 2001 at a 20 × 20-m grid-point resolution.

The emission estimates were then inputted to the King's College London Air Pollution Toolkit (30) to model and predict the annual mean ambient concentrations of nitrogen dioxide (in $\mu\text{g}/\text{m}^3$). Model inputs included meteorological data from Heathrow airport and detailed data on traffic flow, speeds, and vehicle types from the London Atmospheric Emissions Inventory (31). Air pollution values were linked to schools using the schools' postal codes. Procedures were carried out with the use of ArcGIS system (Environmental Systems Research Institute, Inc., Redlands, California). Air pollution could only be modeled for schools within the greater London area, so it was not possible to derive air pollution data for 7 of the 29 schools in the original RANCH United Kingdom cohort.

Outcome and confounding factors assessment

Cognition. Reading comprehension was measured using the Suffolk Reading Scale 2 (32). Episodic memory was measured using a task adapted from the Child Memory Scale (33) that assessed time-delayed conceptual recall, information recall, and recognition of 2 stories presented on compact disc. A modified version of "The Search and Memory Task" (34) was used to assess working memory. See Clark et al. (3) for further details.

Health. Parents completed a self-report questionnaire that included questions on sociodemographic factors, as well as questions on the perceived health of their children (very good/good versus fair/poor/very poor) and psychological distress measured using the parental version of the Strengths and Difficulties Questionnaire (35). We used a continuous Strengths and Difficulties Questionnaire score in our analyses. Blood pressure was assessed in half of the United Kingdom sample following a standard protocol (13) using automatic blood pressure meters (OMRON 711, OMNILA-BO International BV, Breda, the Netherlands). We used the mean of 3 blood pressure measurements in our analyses.

Confounding factors. Data on a number of potential confounders were available (2), including socioeconomic position (employment status, housing tenure, home crowding (>1.5 people per room at home)), maternal educational level, ethnicity, and main language spoken at home (Table 1). Blood pressure analyses were adjusted for premature birth (before gestational week 36), self-reported parental high blood pressure, birth weight (<2,500 g vs. $\geq 2,500$ g), cuff size of blood pressure monitor, temperature during testing ($^{\circ}\text{C}$), and body mass index (weight (kg)/height (m^2)) (13).

Procedure

Group testing was carried out in the classroom in the spring of 2002 and the cognitive tests and child questionnaire were administered as part of a 2-hour testing session conducted in the morning. Written consent was obtained from parents and children. Each child took home a questionnaire for his or her parent.

Analysis

Data were analyzed using the STATA xtmixed command for multilevel modeling (StataCorp LP, College Station, Texas), which enabled variables at the school level (e.g., air pollution) and the individual level (e.g. home ownership) to be fitted in the same model. Beta values, 95% confidence intervals, and *P* values for each variable were obtained. Spearman's rho bivariate correlations were calculated to assess the strength of association between nitrogen dioxide and the noise exposure at school measures, as nitrogen dioxide was not normally distributed.

As air pollution data were available for 22 of the original 29 schools sampled in the United Kingdom RANCH cohort, descriptive statistics were run to compare characteristics of the air pollution subsample data with the original RANCH United Kingdom sample. We fitted multilevel regression models to examine the associations between aircraft and road traffic noise exposure and child cognition and health and adjusted those models for sociodemographic factors to see if the original findings (2, 3, 13) could be replicated in the United Kingdom sample and the United Kingdom air pollution subsample.

Multilevel linear and logistic regression models were used to examine the associations between air pollution and the child cognition and health outcomes. Model 1 included nitrogen dioxide levels and was adjusted for age, gender, mother's educational level, parental employment status, crowding in the home, home ownership, long-standing illness, main language spoken at home, parental support for school work, and classroom window glazing. Model 2 was additionally adjusted for aircraft and road traffic noise exposure at school. We then examined multiplicative interactions between noise exposure and air pollution. For the blood pressure analyses, model 1 was additionally adjusted for body mass index, blood pressure cuff size, room temperature, birth weight, parental high blood pressure, and prematurity. To maximize power in the analyses, complete case analyses were conducted, resulting in a different number of participants for each outcome.

RESULTS

Correlations between noise exposure and air pollution at school

The correlation between nitrogen dioxide levels with aircraft noise exposure was moderate ($r=0.41$, $P<0.01$). Similarly, the correlation between road traffic noise exposure at school and nitrogen dioxide was also modest ($r=0.46$, $P<0.01$).

Comparison of the sample with and without air pollution data at school

Data on air pollution at school were available for 75% ($n=719$) of the original United Kingdom sample ($n=960$). Descriptive analyses revealed few differences between the samples with and without air pollution data (Table 1). Aircraft noise exposure and road traffic noise exposure in

Table 1. Comparison of the Exposure, Cognitive, and Health Outcome Scores and the Sociodemographic Background Variables, United Kingdom RANCH Project, 2001–2003

Characteristic	Subsample With Air Pollution Data (n = 719)			Sample Without Air Pollution Data (n = 241)			Difference Between the Samples With and Without Air Pollution Data ^a		
	Range	Mean (SD)	%	Range	Mean (SD)	%	t	χ^2	P Value
Exposure data									
Aircraft noise exposure at school, dBA	34–68	54 (10.6)		46–59	52 (3.83)		3.60		<0.01
Road traffic noise exposure at school, dBA	37–67	50 (7.7)		47–63	52 (5.04)		–4.78		<0.01
Nitrogen dioxide at school, $\mu\text{g}/\text{m}^3$	29.41–79.88	42.73 (10.60)		N/A					N/A
Cognitive outcomes									
Reading comprehension	–1.49–2.51	0.20 (1.13)		–1.49–2.51	0.23 (1.11)		–0.36		0.72
Recognition memory	15–30	25.10 (2.63)		14–30	24.78 (2.75)		1.54		0.12
Information recall	0–30.5	19.02 (5.31)		0–29	18.06 (5.86)		2.30		0.02
Conceptual recall	0–7.5	5.25 (1.37)		0–7.5	5.04 (1.53)		1.93		0.06
Working memory	–11–32	15.02 (7.37)		–13–32	14.50 (7.85)		0.84		0.40
Health outcomes									
Overall Strengths and Difficulties Questionnaire score	0–34	10.16 (6.02)		0–29	9.79 (5.63)		0.81		0.42
Very good/good self-rated health			82.7			80.8		4.43	0.51
Fair/poor/very poor self-rated health			17.3			19.2			
Systolic blood pressure ^b	85–141	108.4 (10.1)		91–135	110.5 (8.0)		–1.89		0.06
Diastolic blood pressure ^b	49–106	67.1 (8.1)		46–82	66.9 (7.5)		0.16		0.87
Sociodemographic factors									
Age	8 years, 10 months–11 years, 11 months	10 years, 3 months		8 years, 10 months–11 years, 11 months	10 years, 3 months		–0.78		0.43
Male			45.6			43.6		0.30	0.58
Female			54.4			56.4			
Parent(s) not employed			22.7			22.9		0.004	0.95
Parent(s) employed			77.3			77.1			
Home overcrowded			21.7			25.7		1.53	0.22

Table continues

Table 1. Continued

Characteristic	Subsample With Air Pollution Data (n = 719)			Sample Without Air Pollution Data (n = 241)			Difference Between the Samples With and Without Air Pollution Data ^a		
	Range	Mean (SD)	%	Range	Mean (SD)	%	t	χ^2	P Value
Home not owned/ mortgaged			42.5			41.0		0.16	0.67
Child has long- standing illness			26.6			25.7		0.07	0.79
Child speaks other language at home			20.3			27.0		4.67	0.03
Classroom has single window glazing			57.3			74.7		73.23	<0.01
Mother's educational level ^b	0.004–0.853	0.48 (0.28)		0.004–0.853	0.56 (0.28)		–4.28		<0.01
Parental support scale	4–12	10.2 (2.0)		5–12	10.2 (1.9)		–0.40		0.69
Small blood pressure cuff size ^c			5.8			1.3		2.55	0.11
Low birth weight (<2,500 g) ^c			9.4			8.0		0.14	0.71
Premature birth (before gestational week 36) ^c			12.0			14.7		0.40	0.53
Parent(s) with high blood pressure ^b			20.3			25.3		0.89	0.35
Body mass index ^{c,d}	9–23	13.3 (2.32)		10–18	13.0 (1.71)		1.31		0.19
Temperature during blood pressure measurement, °C ^c	20–27	22.9 (1.63)		21–26	23.8 (1.35)		–4.47		<0.01

Abbreviations: dB(A), sound level in decibels A-weighted to approximate the typical sensitivity of the human ear; N/A, not applicable; RANCH, Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health; SD, standard deviation.

^a χ^2 tests were used for categorical variables and *t* tests were used for continuous variables to detect differences between the samples with and without air pollution data.

^b Measured using a relative inequality index based on a ranked index of standard qualifications in each country resulting in a standardized score ranging from 0.01 to 1.00.

^c These factors were only included as confounders/covariates in the blood pressure regression models and the numbers were reduced. There were 276 for whom we had air pollution data and 75 for whom we did not.

^d Weight (kg)/height (m)².

the air pollution subsample were slightly higher: Schools with lower noise exposure levels were also schools for which emission data were not available. There were no differences in cognitive or health outcomes or in socio-demographic factors between the samples except for the fact that the air pollution subsample had slightly lower information recall test scores, were more likely to speak English at home, and had mothers with lower educational levels.

Table 2 shows a comparison of the multilevel regression models for aircraft and road traffic noise associations with cognition and health in the original United Kingdom RANCH sample ($n = 960$) and the air pollution subsample ($n = 719$). We observed associations of similar magnitudes between aircraft and road traffic noise and cognition and health. In the air pollution subsample, aircraft noise exposure at school was significantly associated with children's recognition memory and conceptual recall. Associations with reading comprehension and information recall were borderline significant, and there were no associations with health (Table 2). No associations between road traffic noise and children's cognition or health were observed (Table 2).

The association that we found between aircraft noise exposure and recognition memory replicates that from analyses of the cross-national data (2). The borderline association for reading comprehension replicates and is of a magnitude similar to that from previous analyses of the United Kingdom RANCH data (3). We did not replicate the cross-national findings of an association between road traffic noise and conceptual or information recall (2) in either sample. Neither the cross-national nor the United Kingdom sample data set showed a significant association between aircraft noise and conceptual recall; however, the air pollution subsample did show such an association. There were no associations between aircraft noise or road traffic noise at school and psychological distress, self-rated health, or blood pressure (Table 2) in either sample, replicating the findings of previous analyses (2, 13).

Associations between air pollution, aircraft noise, and road traffic noise at school and children's cognition

After adjusting for sociodemographic factors, we found that nitrogen dioxide levels at school were not significantly associated with children's reading comprehension, recognition memory, information recall, conceptual recall, or working memory, either before or after adjustment for aircraft and road traffic noise exposure at school (Table 3). Overall, adjustment for air pollution at school had little influence on the associations previously observed between aircraft noise exposure at school and children's cognition (Table 3). Aircraft noise exposure at school remained significantly associated with poorer recognition memory, reading comprehension, information recall, and conceptual recall. There were no significant

associations between road traffic noise exposure and cognition either before or after adjustment for air pollution at school.

Associations between air pollution, aircraft noise, and road traffic noise at school and children's health

There were no significant associations of nitrogen dioxide at school with children's psychological distress, systolic blood pressure, diastolic blood pressure, or self-rated health either before or after adjustment for aircraft noise and road traffic noise at school (Table 4).

Does air pollution moderate associations of aircraft noise and road traffic noise at school with children's health and cognition?

Air pollution did not moderate the associations between noise exposure and children's cognition or health. One exception was that road traffic noise exposure was associated with poorer recognition memory for children with lower nitrogen dioxide exposure ($\beta = -0.07$, $P < 0.05$, $n = 314$) compared with children higher nitrogen dioxide exposure ($\beta = 0.03$, $P = 0.13$, $n = 327$).

DISCUSSION

In the present article, we explored the associations between air pollution at school and children's cognition and health in a sample of 9–10-year-old children attending schools near London Heathrow airport. There were 4 main findings. First, there were moderate correlations of both aircraft and road traffic noise exposure at school with air pollution measured at the school. Second, there was no evidence of a relation between air pollution (nitrogen dioxide) and a range of children's cognitive and health outcomes. Third, associations between aircraft noise exposure and children's cognition could not be fully explained by air pollution. No associations between road traffic noise exposure and children's cognition were observed, either before or after adjustment for air pollution. Finally, there was little evidence that air pollution moderated the association of noise exposure on children's cognition. These results raise concerns regarding the influence of chronic aircraft noise on children's cognitive abilities.

To our knowledge, this is one of the first studies to examine the impact of both environmental noise exposure and air pollution on children's cognition and health. Air pollution was not significantly associated with a range of cognitive outcomes, either before or after adjustment for environmental noise exposure. These findings contrast with some previous studies, which found associations between air pollution and a range of cognitive abilities, including verbal and nonverbal intelligence, vocabulary, attention, and memory after adjustment for socioeconomic factors (19–21). There are several explanations for the difference in our findings compared with previous studies. Despite adjusting for socioeconomic factors, residual unmeasured confounding remains possible in all the studies. There may be differences in air pollution exposure and cognitive

Table 2. Multilevel Model Parameter Estimates for the Impact of Aircraft and Road Traffic Noise at School on Children's Cognitive Performance and Health Outcomes, United Kingdom RANCH Project, 2001–2003

Variable	Aircraft and Road Traffic Noise at School Adjusted for Sociodemographic Factors ^a							
	Original Sample (n = 960)				Air Pollution Subsample (n = 719)			
	No. of Participants	β^b	95% CI	P Value	No. of Participants	β^b	95% CI	P Value
Cognitive outcomes								
Reading comprehension	864				651			
Road traffic noise		-0.001	-0.014, 0.011	0.80		-0.002	-0.017, 0.013	0.77
Aircraft noise		-0.010	-0.020, 0.0005	0.06		-0.011	-0.022, 0.00021	0.05
Recognition memory	844				641			
Road traffic noise		-0.012	-0.046, 0.021	0.47		-0.012	-0.048, 0.023	0.50
Aircraft noise		-0.035*	-0.061, -0.009	0.01		-0.042*	-0.069, -0.016	<0.01
Information recall	837				638			
Road traffic noise		0.039	-0.030, 0.108	0.27		0.040	-0.014, 0.094	0.14
Aircraft noise		-0.025	-0.080, 0.028	0.35		-0.040	-0.082, 0.001	0.06
Conceptual recall	834				636			
Road traffic noise		-0.007	-0.008, 0.022	0.37		0.007	-0.007, 0.021	0.31
Aircraft noise		-0.011	-0.023, 0.001	<0.01		-0.015*	-0.025, -0.004	<0.01
Working memory	785				580			
Road traffic noise		0.038	-0.063, 0.142	0.45		0.036	-0.096, 0.167	0.60
Aircraft noise		-0.004	-0.063, 0.142	0.92		0.00077	-0.096, 0.097	0.99
Health outcomes								
Psychological distress	842				634			
Road traffic noise		-0.025	-0.084, 0.032	0.38		-0.030	-0.093, 0.033	0.35
Aircraft noise		-0.017	-0.064, 0.029	0.46		-0.023	-0.073, 0.026	0.36
Self-rated health	868				655			
Road traffic noise		0.0006	-0.024, 0.025	0.96		0.003	-0.024, 0.030	0.82
Aircraft noise		0.002	-0.018, 0.022	0.83		0.007	-0.015, 0.028	0.54
Systolic blood pressure	351				276			
Road traffic noise		-0.09	-0.25, 0.08	0.22		-0.092	-0.303, 0.118	0.39
Aircraft noise		0.02	-0.12, 0.15	0.77		0.024	-0.131, 0.179	0.76
Diastolic blood pressure	351				276			
Road traffic noise		0.02	-0.11, 0.15	0.76		0.042	-0.125, 0.211	0.61
Aircraft noise		0.01	-0.09, 0.12	0.83		0.019	-0.104, 0.144	0.75

Abbreviations: CI, confidence interval; RANCH, Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health.

* $P \leq 0.05$.

^a All models were adjusted for age, gender, employment status, crowding, home ownership, mother's educational level, long-standing illness, main language spoken at home, parental support for schoolwork, and classroom window glazing type.

^b Per 1-dB increase in road traffic noise or aircraft noise.

assessment between studies. Associations may be found at higher exposure levels: In our sample, the range of exposure to air pollution was low to moderate. Associations may also differ by city. Studies have assessed air pollution in the school environment (20) or the home environment (19, 21), which could also influence the findings. There may be error associated with school exposure, as children

spend more time at home, which could account for our null findings. Further cross-national large studies examining exposure-effect relations between air pollution exposure and a range of cognitive abilities would further inform the field.

Overall, our findings confirm those of studies that have demonstrated associations between environmental noise and children's cognition (1, 4, 5) after taking air pollution

Table 3. Multilevel Model Parameter Estimates for Nitrogen Dioxide Levels at School on Children's Cognitive Performance, With Further Adjustment for Aircraft and Road Traffic Noise Exposure at School, in the United Kingdom Air Pollution Subsample of the RANCH Project, 2001–2003 ($n = 719$)

Variable	No. of Participants	Air Pollution at School Adjusted for Sociodemographic Factors ^a			Air Pollution, Aircraft Noise, and Road Traffic Noise at School Adjusted for Sociodemographic Factors ^a		
		β^b	95% CI	P Value	β^b	95% CI	P Value
Reading comprehension	651						
Nitrogen dioxide		0.00041	−0.013, 0.014	0.95	0.004	−0.009, 0.018	0.53
Road traffic noise					−0.004	−0.019, 0.012	0.65
Aircraft noise					−0.012*	−0.023, −0.000063	0.05
Recognition memory	641						
nitrogen dioxide		−0.005	−0.041, 0.031	0.78	0.012	−0.021, 0.044	0.48
Road traffic noise					−0.016	−0.054, 0.022	0.40
Aircraft noise					−0.045*	−0.073, −0.017	<0.01
Information recall	638						
Nitrogen dioxide		0.012	−0.036, 0.061	0.62	0.015	−0.033, 0.062	0.54
Road traffic noise					0.036	−0.020, 0.092	0.21
Aircraft noise					−0.043*	−0.086, −0.000036	0.05
Conceptual recall	636						
Nitrogen dioxide		−0.002	−0.015, 0.011	0.79	0.00023	−0.012, 0.013	0.97
Road traffic noise					0.007	−0.008, 0.022	0.34
Aircraft noise					−0.015*	−0.026, −0.003	0.01
Working memory	580						
Nitrogen dioxide		0.036	−0.174, 0.246	0.74	0.003	−0.295, 0.301	0.98
Road traffic noise					0.034	−0.141, 0.209	0.70
Aircraft noise					0.00086	−0.109, 0.111	0.99

Abbreviations: CI, confidence interval; RANCH, Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health.

* $P \leq 0.05$.

^a All models were adjusted for age, gender, employment status, crowding, home ownership, mother's educational level, long-standing illness, main language spoken at home, parental support for schoolwork, and classroom window glazing type.

^b Per 1-dB increase in road traffic noise or aircraft noise or a 1-point increase in nitrogen dioxide ($\mu\text{g}/\text{m}^3$).

into account. Aircraft noise exposure at school remained significantly associated with poorer recognition memory, reading comprehension, information recall, and conceptual recall after adjustment for nitrogen dioxide levels. Taken as a whole, these findings suggest studies that have found associations between environmental noise and children's health and cognition seem unlikely to have been seriously confounded by air pollution, although this conclusion may differ for samples with greater air pollution exposure.

However, conclusions in terms of whether air pollution confounds associations between road traffic noise exposure and children's cognition are less clear, as we failed to replicate the original cross-national RANCH finding of associations between road traffic noise exposure and improved conceptual and information recall (2) in either the original United Kingdom RANCH sample or the air pollution subsample and subsequently found no associations after adjustment for air pollution. Comparison of the original United Kingdom RANCH sample with the air pollution subsample suggests that the subsample had slightly higher noise exposures and lower maternal educational levels, were more likely to speak English at home, and had slightly higher

scores on the information recall test. Overall, these differences seem unlikely to explain the lack of replication of the original RANCH road traffic noise findings for conceptual and information recall, findings that were themselves unexpected (2) and have yet to be replicated in another sample.

The finding of a significant association between aircraft noise exposure and conceptual and information recall was unexpected, as analyses of the larger cross-national (2) and United Kingdom sample did not show a significant association. It seems counterintuitive that a significant association would be found in a slightly smaller subsample, but the coefficients observed were only slightly larger in magnitude than those in the cross-national and United Kingdom samples. Given the lack of association in the better-powered cross-national data for these cognitive outcomes, these findings should be interpreted with caution.

To our knowledge, no studies have examined associations of air pollution with child health other than with respiratory health (17, 18). We found no associations between air pollution at school and a range of children's health outcomes, including psychological distress, self-rated health, and systolic and diastolic blood pressures.

Table 4. Multilevel Model Parameter Estimates for Aircraft and Road Traffic Noise at School and Nitrogen Dioxide Levels at School on Children's Health in the United Kingdom Air Pollution Subsample of the RANCH Project, 2001–2003 ($n = 719$)

Variable	No. of Participants	Air Pollution at School Adjusted for Sociodemographic Factors ^a			Air Pollution, Aircraft Noise, and Road Traffic Noise at School Adjusted for Sociodemographic Factors ^a		
		β^b	95% CI	P Value	β^b	95% CI	P Value
Psychological distress	634						
Nitrogen dioxide		0.012	−0.042, 0.067	0.67	0.025	−0.033, 0.083	0.40
Road traffic noise					−0.037	−0.104, 0.029	0.27
Aircraft noise					−0.028	−0.079, 0.023	0.28
Self-rated health	655						
Nitrogen dioxide		0.013	−0.006, 0.033	0.18	0.013	−0.008, 0.033	0.22
Road traffic noise					−0.00020	−0.027, 0.027	0.99
Aircraft noise					0.004	−0.018, 0.026	0.70
Systolic blood pressure	276						
Nitrogen dioxide		0.058	−0.092, 0.210	0.45	0.070	−0.120, 0.259	0.47
Road traffic noise					−0.102	−0.31, 0.11	0.35
Aircraft noise					0.017	−0.139, 0.174	0.83
Diastolic blood pressure	276						
Nitrogen dioxide		0.033	−0.084, 0.151	0.58	0.088	−0.059, 0.236	0.24
Road traffic noise					0.030	−0.136, 0.195	0.73
Aircraft noise					0.012	−0.110, 0.134	0.85

Abbreviations: CI, confidence interval; RANCH, Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health.

^a All models adjusted for age, gender, employment status, crowding, home ownership, mother's educational level, long-standing illness, main language spoken at home, parental support for schoolwork, and classroom window glazing type except the blood pressure models, which were additionally adjusted for body mass index, cuff-size, room temperature, birth weight, parental high blood pressure, and prematurity.

^b Per 1-dB increase in road traffic noise or aircraft noise or a 1-point increase in nitrogen dioxide ($\mu\text{g}/\text{m}^3$).

Thus, although there is a consensus that air pollution is associated with hypertension and cardiovascular death in adults (36, 37), our findings suggest that no associations with blood pressure are observable for children. This probably reflects the length of exposure required for the cardiovascular effects of air pollution to develop but could also reflect a lack of power to detect associations in our smaller blood pressure subsample or the moderate levels of pollution examined.

Few studies have examined whether air pollution moderates associations between environmental noise exposure and children's cognition and health. Van Kempen et al. (25) found that children with high air pollution exposure experienced shorter reaction times with high road traffic noise exposure. We found no evidence that air pollution moderated associations, with the exception that road traffic noise exposure was associated with poorer recognition memory for children with lower nitrogen dioxide exposure at school compared with children with higher nitrogen dioxide exposure at school. It is unclear by what mechanism lower levels of air pollution might impact the association between road traffic noise and recognition memory. This could be a chance finding given the number of interactions examined, and it needs to be replicated in a study with a wider range of air pollution exposures.

There are several limitations to the study that may influence the generalizability of the findings regarding air

pollution. The sample lacks schools with high levels of air pollution. Children were not selected for the study based on air pollution exposure at school, which may have biased the distribution of air pollution levels in our sample. Data from participants attending 7 of 29 schools were excluded from the analyses because no air pollution data were available. We were restricted to examining the associations for air pollution at school and lacked information about air pollution exposure at home, which may be important (25). We could not model particulate matter less than 2.5 μm in diameter or black carbon, which could influence cognitive outcomes (19, 23, 24). Exposure misclassification associated with modeling air pollution exposure is a possibility, and the accuracy of estimation may differ for noise and air pollution.

The present study is the largest to date that examined the impact of exposure to both environmental noise and air pollution at school on children's health and cognition. Other strengths include the assessment of a wide-range of cognitive and health outcomes, a sample drawn from a wide range of noise exposure levels, adjustment for a wide-range of individual confounding socioeconomic factors, and the use of multilevel modeling to take school- and individual-level variation into account.

The results of this project have implications for national and local authorities involved in public health, transport planning, and land-use planning. In terms of policy

implications, the RANCH project findings indicate that a chronic environmental stressor—aircraft noise exposure at school—could impair cognitive development in children, specifically reading comprehension and memory. Schools exposed to high levels of aircraft noise are not healthy educational environments.

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REFERENCES

- Hygge S, Evans GW, Bullinger M. A prospective study of some effects of aircraft noise on cognitive performance in schoolchildren. *Psychol Sci*. 2002;13(5):469–474.
- Stansfeld SA, Berglund B, Clark C, et al. Aircraft and road traffic noise and children's cognition and health: a cross-national study. RANCH Study Team. *Lancet*. 2005;365(9475):1942–1949.
- Clark C, Martin R, van Kempen E, et al. Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension: the RANCH Project. *Am J Epidemiol*. 2006;163(1):27–37.
- Lercher P, Evans GW, Meis M. Ambient noise and cognitive processes among primary schoolchildren. *Environ Behav*. 2003;35(6):725–735.
- Haines MM, Stansfeld SA, Brentnall S, et al. The West London Schools Study: the effects of chronic aircraft noise exposure on child health. *Psychol Med*. 2001;31(8):1385–1396.
- Evans GW, Hygge S. Noise and performance in children and adults. In: Luxon L, Prasher D, eds. *Noise and Its Effects*. London, United Kingdom: Whurr Publishers; 2007:549–566.
- Evans G, Lepore S. Non-auditory effects of noise on children: a critical review. *Child Environ*. 1993;10(1):42–72.
- Evans GW, Stecker R. Motivational consequences of environmental stress. *J Environ Psychol*. 2004;24(2):143–165.
- Cohen S, Glass DC, Singer JE. Apartment noise, auditory discrimination, and reading ability in children. *J Exp Soc Psychol*. 1973;9(5):407–422.
- Yerkes RM, Dodson JD. The relation of strength of stimulus to rapidity of habit formation. *J Comp Neurol Psychol*. 1908;18(1):459–82.
- Cohen S, Evans GW, Stokols D, et al. *Behavior, Health and Environmental Stress*. New York, NY: Plenum Press; 1986.
- Eagan ME, Anderson G, Nicholas B, et al. *Relation Between Aircraft Noise Reduction in Schools and Standardized Test Scores*. Washington, DC: Federal Interagency Committee on Aviation Noise; 2004.
- van Kempen E, Van Kamp I, Fischer P, et al. Noise exposure and children's blood pressure and heart rate: the RANCH Project. *Occup Environ Med*. 2006;63(9):632–639.
- Belojevic G, Jakovljevic B, Stojanov V, et al. Urban road-traffic noise and blood pressure and heart rate in preschool children. *Environ Int*. 2008;34(2):226–231.
- Stansfeld SA, Clark C, Cameron RM, et al. Aircraft and road traffic noise exposure and children's mental health. *J Environ Psychol*. 2009;29(2):203–207.
- Lercher P, Evans GW, Meis M, et al. Ambient neighbourhood noise and children's mental health. *Occup Environ Med*. 2002;59(6):380–386.
- Grigg J. Air pollution and children's respiratory health—gaps in the global evidence. *Clin Exp Allergy*. 2011;41(8):1072–1075.
- Schwartz J. Air pollution and children's health. *Pediatrics*. 2004;113(4 suppl):1037–1043.
- Suglia SF, Gryparis A, Schwartz J, et al. Association of black carbon with cognition among children in a prospective birth cohort study. *Am J Epidemiol*. 2008;167(3):280–286.
- Wang S, Zhang J, Zeng X, et al. Association of traffic-related air pollution with children's neurobehavioral functions in Quanzhou, China. *Environ Health Perspect*. 2009;117(10):1612–1618.
- Freire C, Ramos R, Puertas R, et al. Association of traffic-related air pollution with cognitive development in children. *J Epidemiol Community Health*. 2010;64(3):223–228.
- Guxens M, Aguilera I, Ballester F, et al. Prenatal exposure to residential air pollution and infant mental development: modulation by antioxidants and detoxification factors. INMA (INfancia y Medio Ambiente) Project. *Environ Health Perspect*. 2011;120(1):144–149.
- Power MC, Weisskopf MG, Alexeeff SE, et al. Traffic-related air pollution and cognitive function in a cohort of older men. *Environ Health Perspect*. 2011;119(5):682–687.
- Fonken LK, Xu X, Weil ZM, et al. Air pollution impairs cognition, provokes depressive-like behaviors and alters

- hippocampal cytokine expression and morphology. *Mol Psychiatry*. 2011;16(10):987–995.
25. van Kempen E, Fischer P, Janssen N, et al. Neurobehavioral effects of exposure to traffic-related air pollution and transportation noise in primary school children. *Environ Rev*. 2012;115:18–25.
 26. Davies HW, Vlaanderen JJ, Henderson SB, et al. Correlation between co-exposures to noise and air pollution from traffic sources. *Occup Environ Med*. 2009;66(5):347–350.
 27. Foraster M, Deltell A, Basagaña X, et al. Local determinants of road traffic noise levels versus determinants of air pollution levels in a Mediterranean city. *Environ Res*. 2011;111(1):177–183.
 28. Her Majesty's Stationary Office. *Calculation of Road Traffic Noise*. London, United Kingdom: Her Majesty's Stationary Office; 1998.
 29. Kelly F, Anderson HR, Armstrong B, et al. The impact of the congestion charging scheme on air quality in London. Part 1: emissions modeling and analysis of air pollution measurements. HEI Health Review Committee. *Res Rep Health Eff Inst*. 2011;(155):5–71.
 30. Tonne C, Beevers S, Armstrong B, et al. Air pollution and mortality benefits of the London Congestion Charge: spatial and socioeconomic inequalities. *Occup Environ Med*. 2008;65(9):620–627.
 31. Greater London Authority. *London Atmospheric Emissions Inventory 2003*. London, United Kingdom: Greater London Authority; 2006.
 32. Hagley F. *The Suffolk Reading Scale 2*. Windsor, Canada: NFER-Nelson; 2002.
 33. Cohen MJ. *Children's Memory Scale Manual*. San Antonio, TX: The Psychological Corporation: Harcourt Brace & Company; 1997.
 34. Hygge S, Boman E, Enmarker I. The effects of road traffic noise and meaningful irrelevant speech on different memory systems. *Scand J Psychol*. 2003;44(1):13–21.
 35. Goodman R. The strengths and difficulties questionnaire: a research note. *J Child Psychol Psychiatry*. 1997;38(5):581–586.
 36. Brook RD. Is air pollution a cause of cardiovascular disease? Updated review and controversies. *Rev Environ Health*. 2007;22(2):115–137.
 37. Brunekreef B, Beelen R, Hoek G, et al. *Effects of Long-Term Exposure to Traffic-Related Air Pollution on Respiratory and Cardiovascular Mortality in the Netherlands: the NLCS-AIR Study*. Research report 139. Boston, MA: Health Effects Institute; 2009.