Noise exposure and children's blood pressure and heart rate:

The RANCH-project.

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MAIN MESSAGES

- This epidemiological field study examines the effects of aircraft and road traffic noise exposure on primary school children's blood pressure around two European airports.
- On the basis of the RANCH results, considered in conjunction with results of previous studies, no univocal conclusions can be drawn about the relationship between community noise and children's blood pressure.

ABSTRACT

Objectives: Conclusions that can be drawn from earlier studies on noise and children's blood pressure are limited due to inconsistent results, methodological problems and the focus on school noise exposure. This paper reports on a study investigating the effects of aircraft and road traffic noise exposure on children's blood pressure and heart rate.

Methods: Participants were 1,283 children, (age 9-11 years) attending 62 primary schools around two European airports. Data were pooled and analyzed using multilevel modelling. Adjustments were made for a range of socio-economic and genetic factors.

Results: After pooling the data, aircraft noise exposure at school was related to a statistically non-significant increase in blood pressure and heart rate. Aircraft noise exposure at home was related to a statistically significant increase in blood pressure. Aircraft noise exposure during the night at home was positively and statistically significantly associated with blood pressure. The findings differed between the samples. Negative associations were found between road traffic noise exposure and blood pressure, which cannot be explained.

Conclusion: On the base of this study and scientific literature no unequivocal conclusions can be drawn about the relationship between community noise and children's blood pressure.

INTRODUCTION

Road and aircraft noise are two of the most important sources of community noise. [1] It has been estimated that approximately 30 percent of the European Union's population is exposed to levels of road traffic noise of more than 55 dB(A); 20 percent of the European population experiences noise levels that are considered unacceptable.[2] Long term noise exposure is associated with a number of effects on health and well-being. These include community responses such as annoyance, sleep disturbance, disturbance of daily activities, and physiological responses such as hearing loss, hypertension and ischemic heart disease.[2]

This paper focuses on blood pressure changes in children. From a public health perspective, blood pressure elevations at population level are undesirable.[3] In relation to noise, blood pressure elevations are regarded as a non-specific response. However, they are typically associated with stress which is hypothesized to arise either as a consequence of the activation of the autonomic nervous system and the endocrine system or as a consequence of the appraisal of noise.[4] [5] With the preponderant influence of lifestyle and genetic predisposition, it is difficult to gain insight into the contribution of noise to cardiovascular disease. This is probably one of the reasons that conclusions from earlier studies investigating the effects of noise exposure on children's blood pressure are limited and inconsistent. Secondly, a number of methodological problems emerge from these earlier studies (e.g. small differences in noise levels between the exposure groups, potential selection bias, a lack of control for socio-economic status factors, differences in insulation and parental history of high blood pressure). [3] [4] [5] Thirdly, most studies usually only focus on exposure at school when investigating the effects of noise exposure on children. It is questionable whether the health effects should be exclusively attributed to the noise exposure in school. The effect of night-time exposure has been hardly investigated in children.[6] This is an important gap in the research, because time-use studies not only show that children spent a lot of time in and around their home, but also that children spend a large part of their time sleeping.[7] [8] Chronic night-time noise exposure might disturb the excretion of stress hormones (such as cortisol) which is affecting children's health [9]

To investigate the possible association between noise exposure and children's blood pressure and heart rate we collected data from children living around Heathrow Airport and Schiphol Airport gathered in the framework of the RANCH project. The aim of this project was to investigate the effects of aircraft and road traffic noise exposure at school on children's cognition and health.[10] In a later stage of the project the home noise exposure levels also became available.

METHODS

Selection and recruitment. Children aged 9-10 years were recruited from primary schools in areas around Heathrow Airport and Schiphol Airport. Schools were selected according to the modelled noise exposure due to both aircraft and road traffic of the school area (expressed as $L_{Aeq,\ 7\text{-}23hr}$), and were matched on indicators of socio-economic status (SES) and ethnicity. Schools for children with special needs were excluded. Since degrees of achievement can appreciably differ between school types in the UK, we excluded non-state schools in the UK from our study; in the Netherlands the degrees of achievement do not differe between school types. Furthermore, we excluded schools with the presence of a dominant noise source other than aircraft or road traffic noise, or at which insulation against noise was above a certain threshold; in the Netherlands all schools with high aircraft noise levels were highly insulated.

Out of 118 primary schools available in the British study area, 30 were invited to participate and all but one agreed. In the Netherlands, out of 366 available schools in the selected areas, 77 schools were invited to participate, and thirty-three agreed. The parents or carers of 2,179 children were approached through the schools by letter. Eventually 2,012 children got permission to take part. In the Netherlands all the children who had permission to take part and who were available on the day of testing had their blood pressure measured (n = 730); in the United Kingdom every second participating child was selected from the class list for blood pressure measurement (n = 553).

Noise exposure assessment using modelled data. Noise exposure was assessed for each child by linking home and/or school addresses to modelled equivalent aircraft and road traffic noise levels. These predict the average outdoor noise exposure during a specified time interval.

In both centres, aircraft noise levels ($L_{Aeq,\ 7\text{-}23\ hr}$, and $L_{Aeq,\ 23\text{-}7hr}$) were obtained from nationally available noise contours for both the home and school situation. In the Netherlands, modelled aircraft noise levels for the year 2001 were obtained from the Dutch National Aerospace Laboratory (NLR).[11] In the United Kingdom modelled aircraft noise levels were based on the 16hr outdoor LAeq contours provided by the Civil Aviation Authority (CAA) for a three month period (July-September) for the year 2000.

In both centres, road traffic noise levels ($L_{Aeq,\ 7\text{-}23\ hr}$) were obtained for the school situation. Road traffic noise levels ($L_{Aeq,\ 7\text{-}23\ hr}$) for the home situation were only available for the Dutch sample. For the calculation of road traffic noise levels in the Netherlands, national standard methods were adopted to obtain grids with resolutions of 25x25m.[12] In the United Kingdom, road traffic noise levels were calculated by means of the UK standard CRTN noise prediction method, using a combination of information including proximity to motorways, A-roads, B-roads and traffic flow data.[22]

Blood pressure. Blood pressure measurements were taken in the afternoon in a quiet room in the school building using automatic blood pressure meters (OMRON 711, OMNILABO International BV). Cuff-sizes of either 15-22 (small) or 22-32 cm (normal) were used. The cuff was placed on the right arm. While the child was seated and after an initial period of five minutes rest, systolic and diastolic blood pressure and heart rate was measured three times with 1-2 minutes intervals by researchers trained according to a standard protocol. Children were not allowed to talk during the measurement session. Body height and weight were measured without shoes or heavy clothing. At the beginning of each session room temperature was assessed. In the data-analysis the mean value of the three blood pressure measurements was used.

Parent questionnaire. Children were given a questionnaire to take home for their mother (preferably), or other carer to complete. The questionnaire provided information on potential confounding factors (e.g. socio-economic status, birth weight, country of birth and parental history of high blood pressure). 84.8% of the parents (n = 1,175) returned the questionnaire.

Statistical analysis. Before running the analyses, the residuals were checked for outliers. Missing values were few, except for parental hypertension (11%) and cuff-size (9%). Because small cuffs were used 95% of the time, the missing cuff sizes in the UK-sample were imputed as small. To produce persistent effects, noise may have to be present for a certain length of time. Therefore, only those children who attended their present school for at least 1 year were included in the analyses.

To take into account the hierarchical data structure (children grouped within school), multi-level modelling was applied, using the MIXED procedure of SAS version 8.1. A two-level random effects model was used. Country was included as a fixed effect. For the school situation the following two models were run: a model including noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at school, age (yrs), sex, ponderosity (weight/height ^{3}), school glazing (single/double/mixed/triple) and country (UK/NL); the second model equals the first model with the addition of indicators for socio-economic status (crowding, home ownership, employment and mother's education), ethnicity (white/non-white), cuff-size (small, normal), room temperature (°C), birth weight (< 2500 gr./ ≥ 2500 gr.), (self-reported) parental high blood pressure (yes/no), pre-maturity (born before week 36), double glazing at home and the other school noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) source. For the home situation the following two models were run: a model including noise exposure at home ($L_{Aeq, 7\text{-}23 hr}$ or $L_{Aeq, 23\text{-}7 hr}$), age (yrs), sex, ponderosity (weight/height ^{3}), double glazing at home (yes/no) and country (UK/NL); the second model equals the first model with the addition of indicators for socio-economic status (crowding, home ownership, employment and mother's education), ethnicity (white/non-white), cuff-size (small, normal), room temperature (°C), birth weight (< 2500 gr./ ≥ 2500 gr.), parental hypertension (yes/no), and pre-maturity (born before week 36).

The variables included in the models were chosen according to the literature. Furthermore, variables were retained in the main analysis if an analysis of covariance showed a significant relation between the confounding factor and aircraft noise exposure and/or road traffic noise exposure and/or blood pressure. As a result of these analyses coefficients (B) and standard errors (SE) were presented indicating the change in blood pressure per dB(A) increase. These were estimated under restricted maximum likelihood estimation. 95% confidence intervals (95%CI) were calculated by means of the estimated standard errors. Statistical significance was tested under full maximum likelihood estimation, using a chi-square test of deviance.

Heterogeneity between the countries was tested in the models on the pooled data by examining the interaction between country and noise exposure.

In order to compare the results of our study systematically with the results of 5 other recent studies that investigated the association between community noise and children's blood pressure, we calculated the blood pressure change (mmHg) per noise level increase and its variance for both systolic and diastolic blood pressure.[13] [14] [15] [16] [17] [18] [19] To this end we evaluated the studies systematically and extracted average blood pressure values that were presented in these studies and their noise levels. This was done in the same way as was done by Van Kempen et al

(2002).[3]

RESULTS

Descriptives. Eventually, the data of 853 children were eligible for data-analysis (see also figure 1).

< Figure 1 to be inserted here>

Table 1 presents the general characteristics of these children and the schools they attended. It shows that: (i) the UK-sample contains fewer employed parents and fewer homeowners; (ii) the children in the UK-sample had a lower average birth weight and had a higher prevalence of pre-maturity than the Dutch sample; (iii) on average the children of the UK-sample have higher blood pressure than the children of the Dutch sample; and (iv) the UK-sample contains relatively more non-white children than the Dutch sample.

TABLE 1. General characteristics of the children included in the analysis and the schools they visit

Characteristic		Overall (n = 853)			UK-sample (n = 351)			NL-sample (n = 502)		
		Mean (SD)[††]	Range	%	Mean (SD)[††]	Range	%	Mean (SD) [††]	Range	%
Number of participating schools		62			29			33		
Girls				51.5			53.3			50.2
Age (yrs)		10.4 (0.5)			10.3 (0.3)			10.5 (0.6)		
Blood pressure measurements										
	Systolic blood pressure (mmHg)	106.8 (10.4)			108.9 (9.7)			105.4 (10.6)		
	Diastolic blood pressure (mmHg)	66.2 (8.3)			67.1 (7.9)			65.6 (8.4)		
	Pulse (beats/min)	83.9 (11.9)			89.4 (11.5)			80.1 (10.7)		
	% small cuff-size used			90.4			95.2			87.1
	Room temperature (^{o}C)	22.4 (2.0)			23.1 (1.6)			22.0 (2.1)		
Biometrics	**ponderosity (kg/m^3)**	12.61 (2.04)			13.25 (2.21)			12.17 (1.77)		
	birth weight < 2500 gram			7.7			9.1			6.8
	premature [#]			7.3			12.5			3.6

Modelled noise exposure levels in dB(A)							
Aircraft noise	**at school ($L_{Aeq,\ 7\text{-}23hr}$)**	58	(34 - 68)	60	(34 - 68)	54	(36 - 63)
	at home ($L_{Aeq,\ 7\text{-}23hr}$)	51.0	(34 - 73)	53.4	(34 - 73)	49.3	(35 - 65)
	at home ($L_{Aeq,\ 23\text{-}7hr}$)	40.9	(28 - 67)	43.2	(28 - 67)	39.2	(29 - 57)
Road traffic noise	**at school ($L_{Aeq,\ 7\text{-}23hr}$)**	56	(34 - 67)	57	(37 - 67)	55	(34 - 62)
	at home ($L_{Aeq,\ 7\text{-}23hr}$)	-		NA[††]		55.7	(28 - 67)
Insulation							
School glazing	**single**		48.4		51.7		45.5
	mixed[‡‡]		3.2		6.9		-
	double		41.9		41.4		42.4
	triple		6.5		-		12.1
Double glazing at child's home			70.1		85.5		59.4

Socio-economic status	**crowded**†	27.9	21.9	31.9
	homeowners	76.0	64.4	84.1
	employed parents‡	88.3	81.2	93.2
Relative inequality index mother's education (scale 0 - 1)§		0.493 (0.279)	0.492 (0.270)	0.493 (0.285)
White British/Dutch*		80.5	68.4	89.8
Parental high blood pressure**		28.3	21.4	33.1

* Ethnicity of the child's mother was used as a proxy for the child's ethnicity. † Crowding is an objective measure of the number of people per room in a dwelling. In the UK, the official definition of crowded from the census is more than 1.5 people per room per dwelling; in the Netherlands crowding is defined as the number of people being smaller/equal to the number of rooms in a dwelling. ‡ This is a measure of the highest employment status in the child's household. In the UK employed means that the parent is working full-time or part-time and in the Netherlands employed means that the parent does paid work for at least 19 hrs a week. § Mother's education was measured using a ranked index of standard qualifications in each country. A relative index was then calculated for this variable, so that comparisons could be made between the different measures in each country (index ranges from 0-1, with higher number indicating low educational attainment). # Prematurity means that the child was born before week 36 of the pregnancy. ** Parental high blood pressure indicated whether one or both parents had high blood pressure and/or used antihypertensive drugs either currently or in the past. †† Abbreviations: n = Sample size; SD = Standard deviation NA = Not available. ‡‡ School buildings containing double and single glazed windows.

Exposure characterisation. In the UK-sample high correlations between home and school aircraft noise levels ($L_{Aeq, 7\text{-}23hr}$) ($L_{Aeq, 7\text{-}23hr}$) were found (r ~ 0.9). High correlations were also found in the Dutch sample between the aircraft noise level at school ($L_{Aeq, 7\text{-}23hr}$) and the aircraft noise level at home (r > 0.7). The correlation between home and school road traffic noise levels ($L_{Aeq, 7\text{-}23hr}$) in the Dutch sample was moderate (r ~ 0.6).

Aircraft noise exposure. The results of multilevel analysis (table 2) show that after pooling the data, aircraft noise exposure at school and at home was related to a statistically significant increase in systolic blood pressure. Only the effect of aircraft noise exposure at home remained when the model was further adjusted for socio-economic status, ethnicity, cuff-size, room temperature, birth weight, parental hypertension, and pre-maturity. Strong associations with systolic blood pressure were found for ponderosity, centre, parental high blood pressure and cuff size.

TABLE 2. The fully adjusted multilevel models† on the pooled sample for noise exposure and systolic blood pressure (only children visiting their school for at least 1 year) (n = 853).

Situation →	**At school**		**At home**	
	Model 1	**Model 2**	**Model 1**	**Model 2**
	B (95% CI)*	**B (95% CI)***	**B (95% CI)***	**B (95% CI)***
Fixed coefficients ↓				
Intercept	78.01 (60.58 – 95.43)	75.01 (55.14 - 94.87)	74.74 (58.39 – 91.08)	69.03 (49.23 – 88.83)
Noise exposure ($L_{Aeq\ 7\text{-}23\ hr}$) in dB(A)				
Air traffic noise at school	0.11 (0.00 – 0.21) ‡	0.08 (-0.02, 0.18)		
Road traffic noise at school		-0.11 (-0.21, 0.00) ‡		
Aircraft noise at home		-	0.14 (0.04 – 0.24) ‡	0.10 (0.00 – 0.20) ‡
UK	1.94 (0.04 – 3.84) ‡	1.95 (-0.01, 3.91) ‡	1.55 (-0.25 – 3.35)	1.68 (-0.33 – 3.68)
Age (yrs)	0.45 (-1.05 – 1.95)	1.08 (-0.40, 2.55)	0.47 (-1.01 – 1.94)	0.90 (-0.57 – 2.37)
Boys	0.50 (-0.81 – 1.80)	0.52 (-0.76, 1.81)	0.50 (-0.81 – 1.80)	0.55 (-0.74 – 1.84)
Ponderosity (kg/m^3)	1.54 (1.21 – 1.88) ‡	2.06 (1.70, 2.43)‡	1.55 (1.22 – 1.89) ‡	2.05 (1.70 – 2.40) ‡
School glazing				
Single	-1.85 (-5.78 – 2.09)	-0.86 (-4.54 , 2.81)		-0.53 (-4.25 – 3.19)
Single and double	-3.32 (-9.38 – 2.73)	-2.03 (-7.63, 3.58)		-1.68 (-7.38 – 4.02)
Double	-1.99 (-5.92 – 1.94)	-1.58 (-5.19, 2.03)		-1.27 (-4.94 – 2.40)
Triple	*Ref*	*Ref*		*Ref*
Double glazing at home		-1.00 (-2.49, 0.48)	-0.58 (-2.08 – 0.93)	-1.03 (-2.52 – 0.46)
Employed		0.84 (-1.28, 2.96)		0.94 (-1.18 – 3.06)
Crowded		0.42 (-1.06, 1.89)		0.47 (-1.00 – 1.94)
Homeowner		1.21 (-0.43, 2.85)		1.31 (-0.34 – 2.96)
Mother's education		-1.26 (-3.68, 1.16)		-1.18 (-3.61 – 1.25)
White British/Dutch		1.06 (-0.79, 2.91)		1.26 (-0.60 – 3.12)
Small cuff size		-8.19 (-10.63, -5.74)‡		-8.06 (-10.51 - -5.61) ‡
Birth weight < 2,500 gr		-2.35 (-5.25, 0.54)		-2.38 (-5.28 – 0.52)
Parental hypertension		1.64 (0.19, 3.09)‡		1.57 (0.12 – 3.02) ‡

Premature		2.61 (-0.41, 5.63)		2.76 (-0.26 – 5.78)
Room temperature (°C)		-0.23 (-0.64, 0.18)		-0.18 (-0.59 – 0.23)
Random parameters				
Level 2: school	4.45 (0.53 – 8.37)	2.72 (-0.57 – 6.01)	3.71 (0.14 – 7.28)	3.07 (-0.30 – 6.44)
Level 1: pupil	91.44 (82.46 – 100.42)	86.83 (78.46 – 95.20)	91.53 (82.55 – 100.51)	86.76 (79.19 – 95.33)

* B = Estimated change in systolic blood pressure (mmHg) per dB(A). 95% CI= 95% Confidence interval calculated by means of the standard error. † The models are additionally evaluated against a model with the noise term excluded. ‡ χ^2-test was statistically significant $\alpha < 0.05$.

Table 3 shows the fully adjusted associations (model 2) between aircraft and road traffic noise exposure at school and at home and blood pressure and heart rate, for the pooled sample and the country-specific samples.

TABLE 3. The association between noise exposure and blood pressure and heart rate changes, after adjustment for confounders (only children visiting their school for at least 1 year)(n = 853) *)

Source of exposure	Place of exposure	Exposure Metric	Outcome	Pooled sample (n = 853)	UK-sample (n = 351)	NL-sample (n = 502)
				B (95% CI) (p) *)	B (95% CI) (p) *)	B (95% CI) (p) *)
Aircraft noise	At school†)	$L_{Aeq,\ 7\text{-}23hr}$	Systolic blood pressure	0.08 (-0.02 – 0.18) (0.10)	0.02 (-0.12 – 0.15) (0.77)	0.17 (0.01 – 0.33) (0.02)
			Diastolic blood pressure	0.05 (-0.04 – 0.14) (0.22)	0.01 (-0.09 – 0.12) (0.83)	0.20 (0.06 – 0.34) (0.00)
			Heart rate	0.05 (-0.06 – 0.15) (0.33)	0.01 (-0.13 – 0.16) (0.86)	0.08 (-0.11 – 0.27) (0.45)
	At home‡)	$L_{Aeq,\ 7\text{-}23hr}$	Systolic blood pressure	0.10 (0.00 – 0.20) (0.04)	0.03 (-0.10 – 0.17) (0.57)	0.17 (0.01 – 0.33) (0.03)
			Diastolic blood pressure	0.08 (-0.01 – 0.17) (0.05)	0.04 (-0.07 – 0.14) (0.43)	0.19 (0.05 – 0.32) (0.00)
			Heart rate	0.02 (-0.08 – 0.13) (0.61)	0.00 (-0.15 – 0.14) (0.95)	0.06 (-0.12 – 0.23) (0.51)
	At home ‡)	$L_{Aeq,\ 23\text{-}7hr}$	Systolic blood pressure	0.09 (0.00 – 0.18) (0.03)	-0.01 (-0.13 – 0.12) (0.97)	0.19 (0.07 – 0.31) (0.00)
			Diastolic blood pressure	0.07 (-0.01 – 0.14) (0.08)	0.04 (-0.06 – 0.14) (0.35)	0.13 (0.01 – 0.24) (0.02)
			Heart rate	0.03 (-0.07 – 0.12) (0.50)	0.01 (-0.13 – 0.16) (0.84)	0.04 (-0.11 – 0.19) (0.55)
Road traffic noise	At school†)	$L_{Aeq,\ 7\text{-}23hr}$	Systolic blood pressure	-0.11 (-0.21 – 0.00) (0.03)	-0.09 (-0.25 – 0.08) (0.22)	-0.14 (-0.27 - -0.01) (0.02)
			Diastolic blood pressure	-0.04 (-0.13 – 0.06) (0.40)	0.02 (-0.11 – 0.15) (0.76)	-0.09 (-0.20 – 0.03) (0.09)
			Heart rate	-0.02 (-0.13 -0.08) (0.62)	-0.11 (-0.28 – 0.07) (0.22)	0.02 (-0.14 – 0.17) (0.80)
	At home ‡)	$L_{Aeq,\ 7\text{-}23hr}$	Systolic blood pressure		NA*)	-0.09 (-0.22 -0.04) (0.16)

Diastolic blood pressure	NA[*)]	-0.07 (-0.18 – 0.04) (0.17)
Heart rate	NA[*)]	0.06 (-0.08 – 0.20) (0.39)

* Abbreviations: B = estimated change in blood pressure or heart rate per dB(A); 95% CI = 95 percent confidence intervals calculated by means of the standard error; n = sample size, p = p-value for association $\alpha < 0.05$, tested by means of a χ^2-test; NA = Data not available; † The model is adjusted for either aircraft or road traffic noise at school, centre (only for the pooled analysis), age, gender, ponderosity, school glazing, double glazing at home, employment status, crowding, home ownership, mother's education, ethnicity, cuff size, birth weight, parental high blood pressure, prematurity, and room temperature. ‡ The model is adjusted for either aircraft or road traffic noise at home, centre (only for the pooled analysis), age, gender, ponderosity, double glazing at home, school glazing, employment status, crowding, home ownership, mother's education, ethnicity, cuff size, birth weight, parental high blood pressure, prematurity, and room temperature

After pooling the data, chronic aircraft noise at school ($L_{Aeq,\,7\text{-}23\,hr}$) was related to a statistically non-significant increase in systolic (χ^2= 2.7, df =1, p= 0.10) and diastolic (χ^2= 1.4, df =1, p= 0.22) blood pressure and heart rate (χ^2= 1.0, df =1, p= 0.33). Chronic aircraft noise at home (expressed as $L_{Aeq,\,7\text{-}23hr}$) was statistically related to systolic (χ^2= 4.2, df =1, p= 0.04) and diastolic (χ^2= 3.9, df =1, p= 0.05) blood pressure: Increases of 0.10 (95 percent confidence interval: 0.00, 0.20) and 0.19 (95 percent confidence interval: 0.05 – 0.32) mmHg/dB(A) were found for systolic and diastolic blood pressure, respectively. Chronic aircraft noise exposure during the night ($L_{Aeq,\,23\text{-}7hr}$) at home was positively associated with blood pressure. Only for systolic blood pressure was this association statistically significant (χ^2= 4.7, df =1, p= 0.03): after pooling the data an increase of 0.09 (95 percent confidence interval: 0.00, 0.18) mmHg/dB(A) was found.

The effect of chronic aircraft noise on blood pressure differed somewhat between the samples: In the Dutch sample chronic aircraft noise exposure at school was related to an increase in blood pressure. Statistically significant increases of 0.17 (95 percent confidence interval: 0.01, 0.33) mmHg/dB(A) and 0.20 (95 percent confidence interval: 0.06, 0.34) mmHg/dB(A) were estimated for systolic and diastolic blood pressure, respectively. In the British sample aircraft noise exposure at school was related to small and statistically non-significant increases in blood pressure. For diastolic blood pressure, the results differed statistically significantly between the samples (Test of heterogeneity: χ^2=7.1, df =1, p=0.01). In relation to chronic aircraft noise at home (expressed as $L_{Aeq,\,7\text{-}23hr}$ and $L_{Aeq,\,23\text{-}7hr}$) similar differences between the samples could be observed (see also table 3).

Road traffic noise exposure. After pooling the data, chronic road traffic noise exposure at school ($L_{Aeq,\,7\text{-}23\,hr}$) was related to a decrease in systolic and diastolic blood pressure. For systolic blood pressure this association was statistically significant: A decrease of –0.11 (95 percent confidence interval: -0.21, 0.00) mmHg/dB(A) was estimated. A negative association was found between chronic road traffic noise exposure and heart rate: chronic road traffic noise exposure was related to a decrease in heart rate; this was statistically not significant. The effect of road traffic noise on blood pressure did not differ between the samples. The effects of road traffic noise exposure ($L_{Aeq,\ 7\text{-}23hr}$) at home were only investigated in the Dutch sample: road traffic noise at home was related to a statistically non-significant decrease in blood pressure.

Comparison with other studies. In Figures 2 and 3, the results of the RANCH study are compared with other recent studies investigating the effects of noise on children's blood pressure. The figures show that small differences in blood pressure can be observed and that the effect of noise exposure on children's blood pressure differs among the studies.

< figures 2 and 3 to be inserted here>

DISCUSSION

Aircraft noise. In this study indications were found for a possible association between chronic aircraft noise and blood pressure. However, the effect of chronic aircraft noise on the blood pressure differed between the samples: in the Dutch sample aircraft noise exposure was related to increased blood pressure; this was not the case in the British sample. Due to the difference in exposure metrics and adjustment for confounders, comparison of the results of the RANCH study with other studies was difficult. Figures 2 and 3 show that for aircraft noise exposure no consistent findings can be seen. The Los Angeles Airport Study showed that both systolic and diastolic blood pressure were higher in the children attending aircraft noise exposed schools than in children attending control schools.[13] [14] Blood pressure differences of 2.9 mmHg for systolic blood pressure and 2.6 mmHg for diastolic blood pressure were found, while the difference in noise exposure levels ($L_{Aeq,\ 1\ hr\ indoor}$) between the exposed and the control group was 18 dB(A). Comparison of the blood pressure between two groups of children living around the old Munich Airport, exposed to high noise levels ($L_{Aeq,\ 24hr}$=68.1 dB(A)) or lower noise levels (($L_{Aeq,\ 24hr}$=59.2 dB(A)) showed that there was an increase of 1.92 mmHg for systolic blood pressure and a decrease of 0.17 mmHg for diastolic blood pressure.[16] [17] Morrell et al. investigated the effects of aircraft noise exposure both at school and at home.[19] After adjustment for confounders, they found that both school and residential aircraft noise levels were negatively but statistically not significantly associated with systolic and diastolic blood pressure; for school exposure, regression coefficients of -0.017 and -0.043 for systolic and diastolic blood pressure were found, corresponding with mean blood pressure differences of 0.5 – 1.3 mmHg across the whole noise range (15-45 ANEI).

Until now the effects of long-term night-time noise exposure on the cardiovascular system were only investigated in adults: In a recent German study the associations between night-time road traffic noise and several cardiovascular outcomes were found to be stronger than the associations for daytime noise.[20] Because the correlations between aircraft noise metrics were high in the RANCH-study, it was not possible to disentangle the effects of school and home exposure (including the night period).

Road traffic noise. In the RANCH-study negative associations were found between chronic road traffic noise exposure and blood pressure. Regecová and Kellerová (1995) found that children attending kindergartens situated in areas with traffic noise levels higher than 60 dB(A) had higher mean blood pressure than children in quiet areas.[15] Mean heart rate values tended to decrease with increasing traffic noise recorded at kindergartens, which was consistent with the findings in the UK-sample. In the Tyrol study, children exposed to higher levels of road and rail traffic noise (L_{dn}>60 dB(A)) had an elevated systolic blood pressure and only slightly elevated heart rate compared to children exposed to noise levels below L_{dn} 50 dB(A).[18] For diastolic blood pressure a decrease was found. Karsdorf and Klappach (1968) found a maximal difference of 16 mmHg for both systolic and diastolic blood pressure in girls, when comparing the blood pressure of children attending a quiet school with that of children attending a noisy school.[21] So the results of previous studies investigating the effects of road traffic noise were not consistent (see also Figures 2 and 3).

A possible explanation for the unexpected road traffic noise effects might be the estimation of exposure to road traffic noise. Since children move to a different classroom each year during their time at school, road traffic noise exposure change. Thus, the road traffic noise levels at the façade of their current classroom might not reflect the average level of exposure during their time at school.[10]

Differences between the samples. As already mentioned, the effect of aircraft noise on the blood pressure differed between the samples. It is not possible to give an unequivocal explanation for these differences. Although noise levels in both samples were calculated according to a standardized protocol, differences in variations in flight patterns and differences in availability of the aircraft- and road traffic fleet between the countries might have played a role. These could have lead to systematic biases and unexpected differences in the outcome.[22] [23] [24] [25] [26] There might be differences in frequency and type of insulation of both schools and homes, which could result in differences in the effect of noise on blood pressure, even though both design and analysis acoounted for the influence of insulation. [10] Differences in schooling system and teachers' attitudes towards noise might have differential effects on the children's reactions to noise.

The British sample contained relatively more non-white children than the Dutch sample; the Dutch non-white group included Turkish and Moroccan children and children with a mixed background, while the British non-white sample included Pakistani and Indian children. Winkelby showed strong differences in blood pressure among different ethnic groups.[27] It appears that hypertension is very common in African cities and in black populations in Britain and the United States.[28] According to the Dutch Heart Foundation the prevalence of high blood pressure among young foreigners (Turkish and Moroccans) varies from two to ten percent; the variation among Dutch natives is four to seven percent.[29] Due to these differences in ethnic composition of the samples, it is possible that statistical adjustment did not lead to a complete comparison. Because of differences in the ethnic composition between the samples, the impact of ethnicity on the association between noise exposure and blood pressure might differ between the British and Dutch samples. This might be a possible explanation for the differences found in the effect of aircraft noise on blood pressure between both samples.

Furthermore, life-style factors such as salt intake and body exercise were not measured but might have played a role. Another factor which might explain the differences is preterm disease. In a prospective cohort study among adults Babisch et al. found that the association between road traffic noise and heart disease was modified by pre-existent disease.[30]

None of the explanations mentioned in this section, can be further investigated on the data available in the RANCH study.

Study strengths and limitations. This study had a relative large sample size; the participants were distributed over a broad exposure range by using a continuous noise exposure measure. To date, most studies investigating the impact of noise exposure have involved between-group comparisons (high vs low) or they have tended to create noise categories (e.g. high, medium, low) by using indicator terms for ordered polyotomous exposure categories. However, it is recognized that the results may be sensitive to decisions about cut-off points used to categorize continuous exposure variables and the method used to assign scores to exposure categories.[31] Furthermore, we were able to take into account a broad range of potential confounders and determinants which were gathered in a uniform way. Unlike previous studies, we took into account the hierarchical structure of the data. Finally, the current study investigated the effects of both school- and home noise exposure, including night-time noise exposure. Despite the availability of these data, it was not possible to disentangle the effects of school- and home exposure due to the high correlation between the aircraft noise metrics. Because the main objective of RANCH was to investigate the effects of noise exposure at school on children's cognition, noise exposure at home was not taken into account during the selection. Based on our study it is therefore not possible to draw definite conclusions about the relative importance of noise exposure at home and at school and possible interactions between home and school noise exposure.

The cross-sectional design of our study limits causal interpretations of the possible relation between noise exposure and blood pressure. The road traffic noise levels at the façade of the children's school, might not reflect the average level exposure during their time at school. This might have biased the outcomes of our results. [10]

Interpretation of the findings. Due to the fact that the results of this study are not fully consistent and the inconsistency in the scientific literature, it is not possible to derive an exposure-effect relationship between noise exposure and children's blood pressure. Additionally, it is unknown whether the effects of noise on blood pressure are reversible like in the Munich Airport study where the differences in reading score between the two exposure groups disappeared after removing the differences in noise exposure.[32] Finally, it is difficult to indicate whether and to which extent slight increases in children's blood pressure can cause possible health risks in later life. The degree of blood pressure elevations found in relation to noise exposure were small and the clinical significance of such minor changes in childhood blood pressure is difficult to determine. The extent of blood pressure elevations found are probably not significant for children during their youth, but could portend elevations later in life that might be health damaging.[33] In the literature it is suggested that increased blood pressure in children strongly predicts hypertension in young adults; essential hypertension and the precursors of cardiovascular disease might originate in childhood.[34] [35] [36] [37] [38] Some studies, investigating the effects of noise exposure on children's blood pressure interpret such findings as indicator of psychophysiological arousal.[16] [17] However, another possibility is that the observed blood pressure elevations are vegetative responses. Since we found significant associations with night-time exposure, blood pressure elevations might also be seen as an effect of sleep disturbance.[20]

CONCLUSION

The relationship between aircraft noise and blood pressure was not fully consistent: in the Dutch sample, blood pressure increased statistically significantly as aircraft noise exposure increased; this was not the case in the British sample. These findings, taken together with those from previous studies, suggest that no univocal conclusions about the association between aircraft noise exposure and blood pressure can be drawn.

The findings for road traffic noise were difficult to interpret, since negative associations were found between chronic road traffic noise exposure and blood pressure. Furthermore, the results of previous studies investigating the effects of road traffic noise were not consistent

Based on our study it is not possible to draw definite conclusions about the relative importance of noise exposure at home and at school and possible interactions. For a better understanding of the underlying mechanisms, more research is necessary to disentangle the effects of home and school noise exposure.

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Competing Interest Statement: No competing interests

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ABBREVIATIONS

RANCH	Road traffic and Aircraft Noise exposure and children's cognition and health: exposure-effect relationships and combined effects.
L_{Aeq}	A-weighted average sound pressure level
$L_{Aeq,\ 7\text{-}23hr}$	The average continuous equivalent sound level within a certain area from 0700 to 2300 hours within a specified period.
dB(A)	Unit of A-weighted sound pressure level, where A-weighted means that the sound pressure levels in various frequency bands across the audible range have been weighted in accordance with differences in hearing sensitivity at different frequencies.
df	Degrees of freedom
mmHg	Millimeters of mercury
ANEI	Australian Noise Exposure Index. This is a noise metric expressing the level of aircraft noise in Australia. As opposed to equivalent noise metrics (such as $L_{Aeq,\ 7\text{-}23hr}$) the ANEI not only takes into account the energy level of noise level events, but also the number of events and day/night loadings from social surveys in Australia.

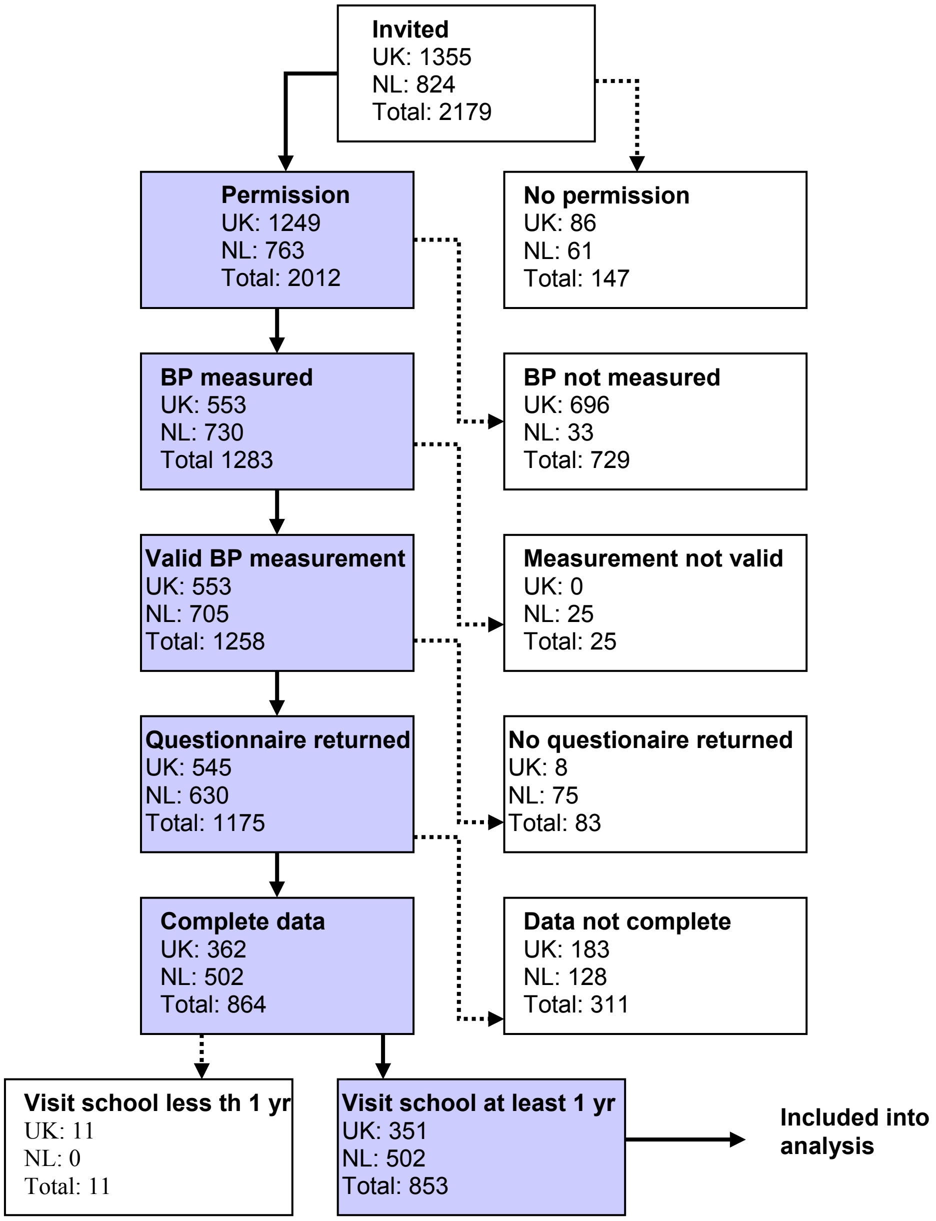

FIGURE 1. Flowchart indicating what has happened with the children that were invited to participate in RANCH. Abbreviations: BP = Blood pressure.

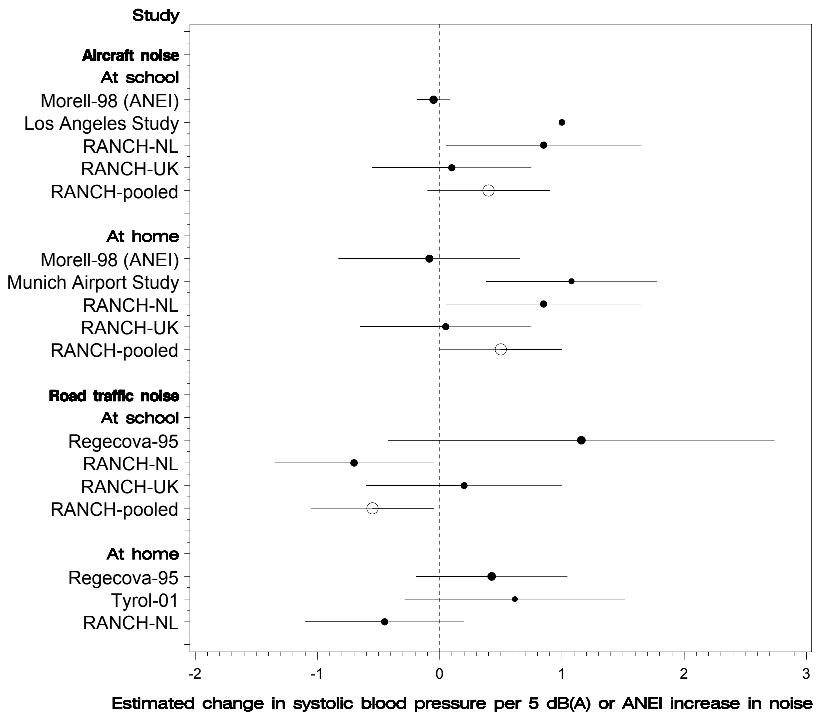

FIGURE 2. The association between noise exposure and systolic blood pressure in children. The dotted vertical line corresponds to no effect of noise exposure; with the exception of Morell-98 [19] the circles and horizontal lines corresponds to the estimated change in blood pressure per 5 dB(A) increase in noise and 95 percent confidence interval. For Morell-98 [19] the circles and horizontal lines correspond to the estimated change in blood pressure per 5 ANEI increase and 95 percent confidence interval. With the exception of the results of the RANCH study and Morell-98 [19], the presented estimates of the other studies were not adjusted for confounders due to the fact that data were not available.

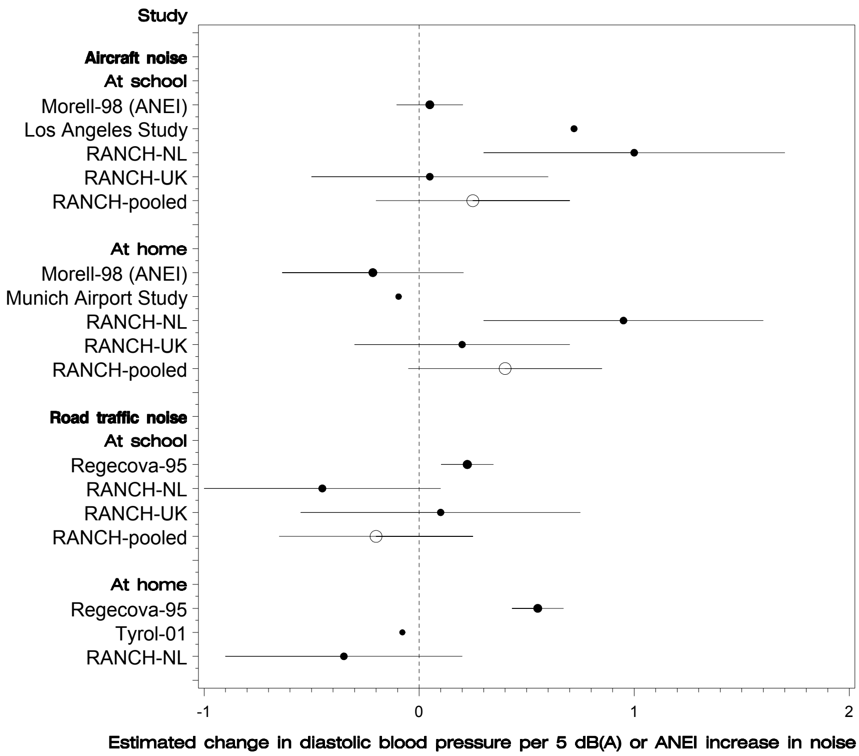

FIGURE 3. The association between noise exposure and diastolic blood pressure in children. The dotted vertical line corresponds to no effect of noise exposure; with the exception of Morell-98 [19] the circles and horizontal lines corresponds to the estimated change in blood pressure per 5 dB(A) increase in noise and 95 percent confidence interval. For Morell-98 [19] the circles and horizontal lines correspond to the estimated change in blood pressure per 5 ANEI increase and 95 percent confidence interval. With the exception of the results of the RANCH study and Morell-98 [19], the presented estimates of the other studies were not adjusted for confounders due to the fact that data were not available.