Childhood peak flow and the Oxford Transport Strategy

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ABSTRACT

Background: Studies of the health effects of traffic interventions are rare. The Oxford Transport Strategy (OTS), implemented in June 1999, involved a wide range of permanent changes designed to reduce congestion in the city centre of Oxford, UK. The impact of the OTS on peak expiratory flow (PEF) and respiratory symptoms among schoolchildren in the city is reported.

Methods: A dynamic cohort of 1389 children aged 6–10 years attending first schools in Oxford was studied. Schools were visited 2–3 times a year for 5-day periods between 1998 and 2000. On each day of each visit children had their PEF measured and were asked about their respiratory symptoms.

Results: Changes in traffic varied across the city. In the whole population, regression analysis of daily PEF adjusting for potential confounders showed statistically significant improvements post-OTS ($\beta = 5.52$ l/min, 95% CI 3.08 to 7.97), but there was no consistent evidence that these improvements varied by changes in traffic exposure. In post-hoc analyses, children currently receiving treatment for asthma tended to experience a greater increase in PEF post-OTS as did children from less affluent homes, although these differences did not reach statistical significance. In each of these groups, greater benefits were observed among those living near roads where traffic levels fell post-OTS.

Conclusions: These findings suggest that traffic management may lead to small localised improvements in childhood respiratory health and that such benefits are limited to children with pre-existing respiratory problems and those from less affluent backgrounds.

It is widely accepted that air pollution has a damaging impact on respiratory health and that children may be particularly susceptible.[1] Research in this area—much of it epidemiological—has influenced public policy on air pollution standards, and traffic interventions may be promoted on the basis of their anticipated health improvements.[2] Studies in Dublin,[3] Utah[4] and Hong Kong[5] have shown that planned (and unplanned) interventions that improve air quality can benefit public health. A recent health impact assessment of the Congestion Charging Scheme in London suggested that a beneficial effect on adult all-cause mortality could be anticipated,[6] but very few studies have examined the direct impact of policies relating to traffic flows. Those that are published have been either of short-term interventions—such as those in Atlanta, USA during the 1996 Summer Olympic Games[7] and Busan, South Korea during the 2002 Summer Asian Games[8]—or of very limited traffic diversions.[9] These offer little guidance for those planning city-wide permanent traffic-calming policies.

Most cities have had to grapple with the issue of increasing traffic, but it is perhaps of particular concern to historic cities where the construction of new roads or the widening of existing roads are not feasible solutions. Oxford, a medium-sized city in south central England, has instituted progressive transport policies for many years, but events in the late 1980s, including an increase in bus traffic post-deregulation, required a revision of existing policy.[10] In 1991, consultants were commissioned to devise a new strategy for dealing with traffic in the city centre and their proposed intervention—the Oxford Transport Strategy (OTS)—was implemented in June 1999. It involved a wide range of changes focused primarily on the city centre from which all traffic was barred from some streets and private vehicles from others. It was expected that these changes would lead to significant alterations in traffic flows in other parts of the city.

The multidisciplinary Environmental Monitoring of an Integrated Transport Strategy (EMITS) research group was established to assess the impact of the OTS on several aspects of life in Oxford.[11] Here we report the effect of the OTS on respiratory health through the study of a dynamic cohort of Oxford schoolchildren.

METHODS

Dynamic cohort study

Two research nurses visited seven primary schools in central Oxford collecting information on all pupils aged 6–10 years. The schools were selected because they were in those areas of the city where the greatest effects of the OTS were anticipated. All students in years 1–3 (ages 6–10 years) were approached and parental consent was obtained by opt-out slip. Of the 1418 children approached, 1389 (98%) took part in the study.

Between 1998 and 2000 we visited schools in the spring and winter for 5 consecutive days (Monday to Friday). Resources allowed additional summer visits in each year to three schools; in the winter of 2000 just three of the seven schools were visited. Visits were scheduled so that there would be approximately equal numbers of observations before and after the implementation of the OTS in June 1999. At the end of each academic year (autumn 1998 and 1999), year 3 students left the study and were replaced by a new group of year 1 students.

For each day of each visit, pupils were asked to answer, using an ordinal scale, questions regarding their respiratory health on the previous day (see fig 1 in online supplement) and to have their peak flow measured using a mini-Wright meter (Clement Clarke Ltd, Harlow, UK). For the latter we recorded the highest value of three reproducible (within 10%) readings. Pupils' heights were measured on the first day of each visit.

Information collected from the children in these ways was supplemented by questionnaires completed by their parents or guardians at the time of recruitment. These provided home addresses and enquired into the medical history of the child and their immediate family, conditions in the home and the ethnicity and social class of the household. Social class was defined by parental occupation using the UK Registrar General's 1990 classification. The six categories, ranging from professional (social class I) to unskilled (social class V) occupations, group people with similar levels of occupational skill. Of the 1389 participating children, we collected parental responses and valid addresses in the Oxford area for 1125 (81%).

Exposure assessment

Address coordinates were obtained using the Ordnance Survey AddressPoint when full address details were provided and CodePoint when only postcodes were available. Traffic data for 217 road segments were supplied by Oxford County Council who used the Simulation and Assignment of Traffic to Urban Road Networks (SATURN) model to estimate traffic flows on a large proportion of the city's road network. A pre-OTS model was generated using data from origin and destination surveys in 1991 and 1997 and calibrated using observed traffic counts. Origin-destination surveys, in which motorists were asked the origin and destination of their journey on the survey day, were conducted by Oxford County Council. The post-OTS model incorporated changes to the network brought in by the OTS and used data from a 2001 origin-destination survey, calibrated by independent traffic count data. Roads with SATURN data were digitised in ArcView GIS V.3.2 (Redlands, California, USA) based on Ordnance Survey Land-Line Plus maps (1:1250). Changes in nitrogen oxide emissions were modelled using 1 km grid squares of SATURN-derived traffic flows.

Statistical analysis

This analysis is confined to the 1125 children for whom both valid home address and parental questionnaire data were available. Four outcomes were studied: daily measures of peak flow and symptoms of self-reported wheeze, runny nose and cough. Raw peak flow values were used in the analyses but regression models adjusted for age and height at the visit. Children were considered to have respiratory or nasal symptoms if they reported any wheeze, cough or runny nose on the day before a school visit. Exposure to traffic and changes resulting from the OTS were estimated by traffic levels on the street nearest the home for the entire cohort and after isolating individuals for whom their nearest modelled street was within 100 m of the home.

For multivariate analysis of daily health outcomes, forward-fitting stepwise generalised estimating equations with exchangeable correlation structure and semi-robust errors were used. In the case of peak flows, normally distributed errors were assumed with identity link. In the case of wheeze, cough and runny nose symptoms, the outcomes were categorised as any or no symptoms on the previous day. Models assumed a binomial distribution with logistic link. Regression models were then stratified by traffic exposure, treatment for asthma, social class and sex to determine how the effect of the OTS varied by changes in traffic level and whether there were any sensitive subgroups.

Statistical analyses were performed using SAS 9.1 (SAS Institute, Cary, North Carolina, USA) and Stata 9 (Stata Corporation, Texas, USA).

RESULTS

Demographic factors

The 1125 participating children were seen, on average, three times over the course of the study period; 434 (39%) were visited both before and after the OTS. At recruitment they ranged in age from 6 to 10 years. The average age was 7.6 years at pre-OTS visits and 7.7 years at post-OTS visits. Approximately equal numbers of boys and girls were recruited (table 1) and 45% were from less affluent homes (social class IIIN–V or unclassified); 34% of parents reported that their children were of non-white ethnicity.

Based on parental reports, 17% of children had current symptoms of wheeze, 18% had had a diagnosis of asthma and 14% were currently taking treatment for the disease (table 1). On self-report, 64% of children reported wheeze, 98% of children reported cough and 92% reported a runny nose at least once during the study period. Mean daily peak flows ranged from 220 l/min to 302 l/min (median 267 l/min), tending to be higher in the spring and summer months. Average daily values of peak flows and prevalences of self-reported respiratory symptoms are summarised in figs 5–8 in the online supplement.

Changes in traffic

Pre-OTS traffic levels in Oxford were on average not very high, but varied considerably by geographical area. Based on the 217 modelled street segments, the average 24 h total traffic flows ranged from 240 to 33 024 vehicles (median 10 416).

Following the OTS there was a small fall in the median total traffic level to 10 147 vehicles/24 h, but changes on individual street segments varied considerably from a reduction of 17 424 vehicles to an increase of 9749 vehicles. Traffic reductions occurred mainly in the city centre where the OTS traffic changes were focused; elsewhere, traffic changes were more variable and correlated with changes in modelled nitrogen oxide emissions (fig 1).

Exposure to traffic

Children tended to live close to the modelled street segments; approximately one-third of their addresses were within 50 m of a modelled street segment and 65% were within 100 m. Only three addresses were further than 1 km.

The changes in traffic observed across the city were reflected in children's exposure. Changes in traffic levels on the street nearest the home ranged from a fall of 11 184 vehicles to an increase of 9240 vehicles (median 95 vehicles/24 h).

Impact of OTS

Regression analysis adjusting for potential confounders showed that daily peak flows were significantly and positively associated with height and age at visit, and that peak flows were significantly reduced in those being treated for asthma and those whose parents smoked (table 2). The model also revealed evidence suggestive of a learning effect, such that peak flows were lower on the first day of the visit and improved over the course of the week. When the pre and post-OTS periods were compared, the adjusted model showed a small but statistically significant improvement in daily peak flows post-OTS ($\beta = 5.52$ l/min, 95% confidence interval (CI) 3.08 to 7.97).

Table 1 Distribution of demographic factors by asthma treatment and social class

		Current treatment for asthma		Social class	
	All subjects	No (n = 916)	Yes (n = 143)	I/II (n = 563)	IIIN–V or unclassified (n = 459)
Age at recruitment (years)					
6	310 (27.6)	256 (28.0)	42 (29.4)	157 (27.9)	128 (27.9)
7	413 (36.7)	343 (37.5)	53 (37.1)	204 (36.2)	177 (38.6)
8	301 (26.8)	236 (25.8)	36 (25.2)	147 (26.1)	117 (25.5)
9	100 (8.9)	80 (8.7)	12 (8.4)	54 (9.6)	37 (8.1)
10	1 (0.1)	1 (0.1)	0	1 (0.2)	0
Sex (female)	587 (52.2)	498 (54.4)	57 (39.9)	300 (53.3)	229 (49.9)
Asthma	203 (18.4)	74 (8.2)	119 (85.6)	99 (17.9)	93 (20.6)
Current wheeze	184 (16.4)	62 (6.8)	120 (83.9)	86 (15.3)	82 (18.0)
Maternal asthma	155 (14.3)	101 (11.4)	45 (32.9)	76 (13.9)	68 (15.4)
Paternal asthma	128 (12.2)	100 (11.7)	24 (18.6)	64 (11.8)	57 (13.5)
First born	461 (41.1)	376 (41.1)	58 (41.1)	266 (47.3)	153 (33.4)
Non-white ethnicity	376 (33.8)	295 (32.4)	57 (40.7)	115 (20.6)	205 (45.2)
Parental smoking in the home	356 (31.9)	293 (32.3)	41 (28.7)	88 (15.9)	225 (49.1)
Mould in the home	198 (18.1)	157 (17.7)	29 (20.7)	81 (14.7)	100 (22.6)
Gas cooker in the home	825 (74.0)	673 (74.3)	105 (73.4)	420 (75.5)	330 (72.4)
Ownership of furry pets	460 (42.3)	387 (43.4)	48 (34.8)	272 (50.0)	162 (36.5)

Data shown as n (%).

Similarly, there was a significant reduction in self-reported wheeze post-OTS after adjusting for potential confounders (odds ratio (OR) 0.77, 95% CI 0.67 to 0.89). There was insufficient variability to allow any meaningful analysis of cough and runny nose.

To determine whether the observed improvement in peak flows was due to a residual learning effect uncontrolled for by the model, a second analysis was limited to measurements made at children's first visits. This showed a similar statistically significant improvement in peak flows post-OTS ($\beta = 7.70$ l/min, 95% CI 1.71 to 13.68).

To explore whether there were sensitive subgroups in the population, the peak flow model was stratified by current treatment for asthma, social class and sex. Although the differences did not reach statistical significance, the effect of OTS was greater in children currently being treated for asthma ($\beta = 10.56$ l/min, 95% CI 3.04 to 18.09) than in those not being treated ($\beta = 4.84$ l/min, 95% CI 2.25 to 7.43) and in those from

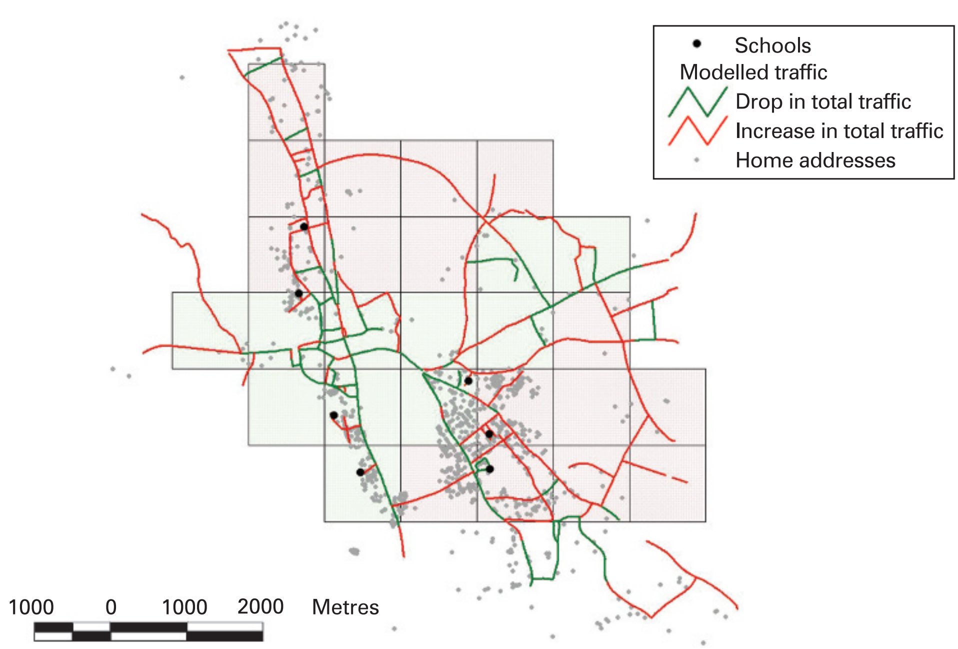

Figure 1 Map of modelled road segments, schools, home addresses and changes in nitrogen oxide emissions in Oxford. The green squares indicate 1 km² areas where modelled emissions fell; the red squares indicate 1 km² areas where modelled emissions increased. © Crown copyright, all rights reserved. Licence number 100019348.

Table 2 Peak flow regression model results (l/min)

	Unadjusted β (95% CI)	Adjusted β (95% CI)
Asthma treatment	−14.45 (−22.90 to −6.01)	−13.57 (−20.70 to −6.44)
Parental smoking	−7.16 (−12.74 to −1.58)	−9.17 (−13.80 to −4.53)
First visit	−32.61 (−34.42 to −30.81)	−11.87 (−13.86 to −9.88)
Winter (Nov–Feb)	−6.24 (−8.01 to −4.46)	1.31 (−0.13 to 2.75)
Height at school visit (cm)	4.91 (4.69 to 5.12)	2.59 (2.31 to 2.86)
Age at school visit (years)	28.52 (27.19 to 29.86)	9.82 (7.92 to 11.72)
Day of the week		
Mon	0	0
Tues	4.38 (3.45 to 5.32)	4.51 (3.56 to 5.45)
Wed	5.93 (4.90 to 6.97)	6.20 (5.15 to 7.26)
Thurs	6.16 (5.10 to 7.22)	6.52 (5.43 to 7.61)
Fri	7.69 (6.49 to 8.88)	7.89 (6.68 to 9.11)
OTS	35.79 (33.66 to 37.91)	5.52 (3.08 to 7.97)

OTS, Oxford Transport Strategy.

less affluent homes (β = 9.22 l/min, 95% CI 5.50 to 12.94) than in more affluent children (β = 2.18 l/min, 95% CI −1.16 to 5.52). Differences between boys and girls were minimal.

To determine whether the effect of the OTS varied by traffic exposure, regression models were stratified by changes in children's exposure to traffic at home. In the whole cohort, when total traffic levels were considered (fig 2), no clear dose-response trend was observed; similar results were obtained when the analysis was restricted to those children living within 100 m of the nearest modelled street. We found no consistent evidence that the improvement in wheeze was related to changes in traffic flows.

When peak flow models stratified by changes in traffic exposure were restricted to potentially sensitive subgroups, however, different patterns emerged (fig 3). Although the confidence intervals overlapped, among children being treated for asthma and, to a lesser extent, children from less affluent homes, the effect of the OTS tended to be greater for children living near streets where traffic levels decreased. There was little visual evidence of a dose-response effect in the other groups.

There was no statistically significant evidence of confounding between change in traffic exposure and current treatment for asthma, although treatment rates tended to be slightly higher where there were reductions in heavy goods vehicle (HGV) traffic (table 3). Similarly, there were no significant differences in social class by change in traffic volume. However, children from less affluent households were more likely to have HGV traffic on their nearest road (pre-OTS 91% vs 84%, p = 0.001; post-OTS 91% vs 86%, p = 0.01).

DISCUSSION

A very large number of epidemiological studies have related childhood respiratory health to road traffic and traffic-related pollution,[7 12–24] but very few have attempted to measure directly changes in health following reductions in traffic flows. Using a simple before-after study of a dynamic cohort of schoolchildren, we have observed improvements in peak flow following a city-wide traffic intervention. These improvements were not consistently linked with reductions in traffic in the cohort overall but, in post hoc analyses of children taking treatment for asthma and from non-professional/managerial households, the improvements associated with the OTS tended to be greater in those living near streets where traffic volumes fell.

We cannot with certainty attribute the improvements we observed to the traffic intervention. Indeed, almost all subgroups—including those not being treated for asthma—experienced either an improvement or no significant change in peak flow post-OTS. Confidence intervals for the observed improvements generally overlapped, suggesting no statistical evidence of a difference. It is likely that traffic exposure near the home reflected only a small part of a child's exposure to the effects of the OTS. Among children being treated for asthma and those from less affluent homes, however, the improvements in peak flows post-OTS tended to be greatest among those living near streets where traffic decreased. Although evidence is mixed, some studies have shown that children with respiratory symptoms or taking respiratory treatments are more sensitive to changes in air quality;[25–27] traffic exposure near the home may be more important for these individuals. The difference in effect by social class may be due to children from less affluent households being more likely to have HGV traffic on the road nearest to their home. It may also be possible that there are other differences between the two groups, leading less affluent children to be more susceptible to traffic changes in Oxford. These may include dietary differences, with less affluent children having a lower intake of antioxidant vitamins which might make them more susceptible to pollutant effects.[28] Other explanations for our findings must include a communal improvement in asthma treatment coincidental with the implementation of the OTS. We do not have the means to investigate further this or other alternative explanations, and

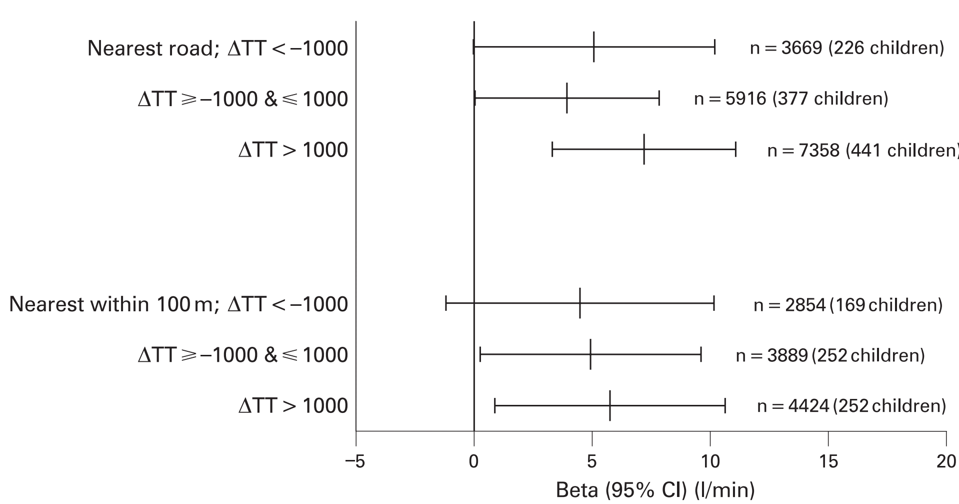

Figure 2 Stratified regression analysis of peak flow by traffic changes in all children. ΔTT, change in total traffic levels.

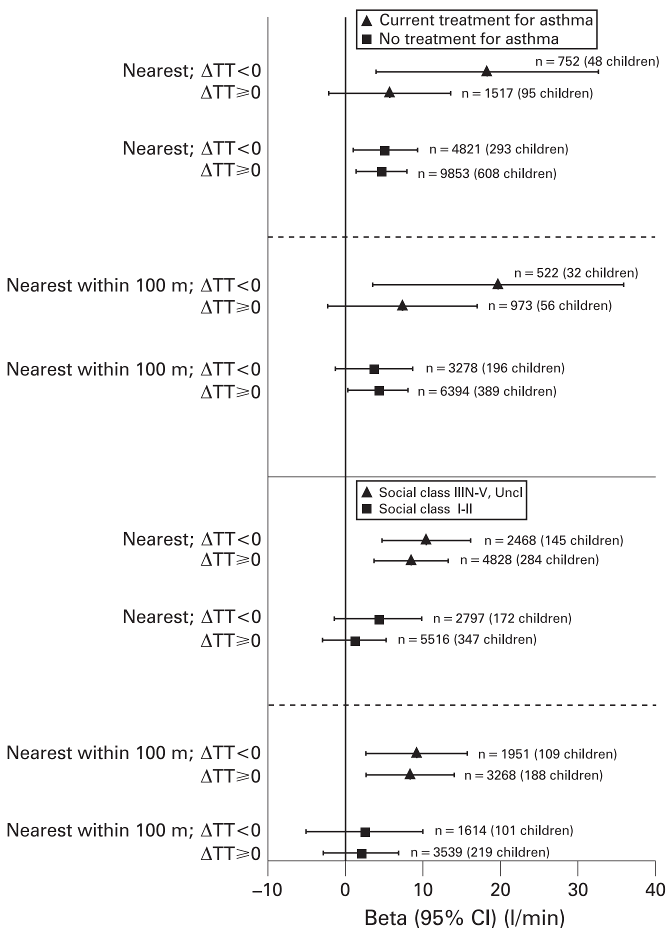

Figure 3 Stratified regression analysis of peak flow by traffic changes and sensitive subgroups. ΔTT, change in total traffic levels.

nor did we include a "control" group in the study since we believed that there would be sufficient heterogeneity of exposure change within our population to make this unnecessary.

We recognise in our approach the possibility of exposure misclassification, some of it perhaps differential. We based traffic exposures on the street nearest the home address. While AddressPoint provides geographical coordinates to an accuracy of 0.1 m where full address details are available, in the few instances where only postcodes were available CodePoint used a slightly less accurate means of assessing geographical location which could lead to misclassification. Children may have moved house during the study period and may have done so for reasons relating to nearby traffic. Since ours was a dynamic cohort, continually supplemented by the arrival of new children, and since we collected home addresses at entry, it is difficult to see how this could have introduced any serious bias away from the null. It is also debatable whether traffic nearest the home truly reflected exposures as we carried out our fieldwork in term time when children spend a quarter of their day in or on the way to and from school. We constructed a weighted exposure estimate that incorporated traffic levels near each child's school, but found little difference from that using home address estimates alone (data available). This is largely a reflection of the very low traffic levels near most of the schools.

Although the observed improvement in peak flow was small and would probably, at an individual level, be clinically insignificant, it was accompanied by an improvement in wheeze and at a population level both may be important. Furthermore, these improvements are important because they suggest that, even in cities with relatively low traffic levels, a traffic intervention may have an impact on respiratory health. European studies that have shown associations between measured traffic volume and respiratory symptoms have generally been based in cities with higher traffic levels than those observed in Oxford during the pre-OTS period. Three-quarters of all road segments in Oxford fall in or below the "low" category of total traffic used in a study in Munich.[29] It is worth noting that the overall change in traffic post-OTS was not large, but there were segments that experienced substantial increases and decreases. Road segments that experienced significant reductions were primarily in the city centre, while the effect was more mixed elsewhere. If our findings are generalisable, then it is probable that greater improvements in health would result from tougher interventions in busier cities.

Parents were, of course, aware of the purpose of the study when their children were recruited. We attempted to avoid any reporting bias by relying on the children to report their own symptoms and by incorporating an objective measurement of respiratory function. We felt that children, even in Oxford, would be unlikely to recognise often subtle changes in nearby traffic flows, especially as most of these were difficult to predict with any certainty. Some young children find it difficult to make reproducible measurements of peak flow and it can be unclear exactly what they mean when they report "wheeze". Peak flows tended to be worse at a child's first school visit and on the first day of each 5-day visit, suggesting learning effects. Our measurements, however, were internally consistent: peak flow was related to age and height and was worse in children taking treatment for asthma, as shown in the reported regression model. The average age at pre-OTS visits was virtually the same as at post-OTS visits (7.6 vs 7.7 years) and

Table 3 Distribution of current asthma treatment and social class by traffic exposure

Change in traffic exposure			Current treatment for asthma N (%)	p Value	Social class IIIN–V, unclassified N (%)	p Value
Nearest street to the home	Total traffic	<0	48 (14.0)	0.75	151 (45.2)	0.89
		⩾0	95 (13.3)		308 (44.8)	
	HGV	<0	60 (16.1)	0.06	176 (49.3)	0.17
		⩾0	67 (11.8)		243 (44.6)	
Nearest street within 100 m of the home	Total traffic	<0	32 (13.9)	0.56	115 (51.3)	0.15
		⩾0	56 (12.3)		202 (45.4)	
	HGV	<0	38 (15.3)	0.14	119 (50.0)	0.70
		⩾0	38 (11.2)		162 (48.4)	

HGV, heavy goods vehicle.

it is unlikely that observed improvements in peak flow and wheeze are due to an older cohort. Moreover, our findings of improvements in both peak flows and wheeze following the OTS are biologically plausible.

EMITS's mandate and the scope of the intervention make the study unique and its findings valuable to traffic planners and public health officials alike. Our results suggest—but do not confirm—that improvements in the respiratory health of young children may be observed after major city-wide traffic changes. Any changes are small but probably valuable when applied to a large population. Children with asthma and those from less advantaged homes may gain greater benefit. These findings offer potentially valuable guidance to other cities planning large-scale traffic interventions, particularly those with historic centres.

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Competing interests: None.

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