Associations between smoke-free vehicle legislation and childhood admissions to hospital for asthma in Scotland: an interrupted time-series analysis of whole-population data

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Summary

Background In Scotland, childhood admissions to hospital for asthma fell from March, 2006, after legislation was introduced to prohibit smoking in public places. In December, 2016, new Scottish legislation banned smoking in vehicles containing a child. We aimed to determine whether the introduction of this new legislation produced additional benefits.

Methods We obtained data on all asthma emergency admissions to hospitals in Scotland between 2000 and 2018 for individuals younger than 16 years. We used interrupted time-series analyses to study changes in monthly incidence of asthma emergency admissions to hospital per 100 000 children after the introduction of smoke-free vehicle legislation, taking into account previous smoke-free interventions. We did subgroup analyses according to age and area deprivation, using the Scottish Index of Multiple Deprivation, and repeated the analyses for a control condition, gastroenteritis, and other respiratory conditions.

Findings Of the 32 342 emergency admissions to hospital for asthma among children younger than 16 years over the 19-year study period (Jan 1, 2000, to Dec 31, 2018), 13 954 (43%) were among children younger than 5 years and 18 388 (57%) were among children aged 5–15 years. After the introduction of smoke-free vehicle legislation, there was a non-significant decline in the slope for monthly emergency admissions to hospital for asthma among children younger than 16 years (–1·21%, 95% CI –2·64 to 0·23) relative to the underlying trend in hospital admissions for childhood asthma. However, children younger than 5 years had a significant decline in the slope for monthly asthma admissions (–1·49%, –2·69 to –0·27) over and above the underlying trend among children in this age group (equivalent to six fewer hospitalisations per year), but no such decline was seen in children aged 5–15 years. Monthly admissions to hospital for asthma fell significantly among children living in the most affluent areas (–2·27%, –4·41 to –0·07) but not among those living in the most deprived areas. We found no change in admissions to hospital for gastroenteritis or other respiratory conditions after the introduction of the smoke-free vehicle legislation.

Interpretation Although legislation banning smoking in vehicles did not affect hospital admissions for severe asthma among children overall or in the older age group, this legislation was associated with a reduction in severe asthma exacerbations requiring hospital admission among preschool children, over and above the underlying trend and previous interventions designed to reduce exposure to second-hand smoke. Similar legislation prohibiting smoking in vehicles that contain children should be adopted in other countries.

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Introduction

Exposure of children to second-hand smoke increases their risk of developing asthma.[1] Estimates of the proportion of cases of childhood asthma attributable to second-hand smoke exposure range from 1·3% to 8·2%.[1] Second-hand smoke exposure also increases the risk of exacerbations among young children who already have asthma.[2]

Many countries, including Scotland, have introduced legislation that prohibits smoking in enclosed public places and workplaces, in accordance with the recommendations contained in Article 8 of the WHO Framework Convention on Tobacco Control.[3] However, exposure of children, especially preschool children, to second-hand smoke occurs primarily in places not covered by public place legislation, such as homes and private vehicles.

In Scotland, exposure to second-hand smoke in homes has reduced over the past two decades.[4] The Scottish legislation, introduced in March, 2006, banning smoking in enclosed public places did not apply to homes. However, this legislation produced additional behavioural changes, resulting in some parents adopting voluntary restrictions on smoking in their homes; this led to substantial reductions in cotinine concentrations among school children,[5] which, in turn, resulted in reductions in

Research in context

Evidence before this study

Exposure of preschool children to second-hand smoke is due mainly to parental smoking in the home or family vehicles and increases the risk of asthma. We searched PubMed from inception up to May 10, 2021, using the following terms: (smoke-free OR second-hand smoke OR ((smoke OR tobacco OR cigarette*) AND exposure) AND (vehicle OR car) AND legislation). Previous studies showed that smoking in cars produced second-hand smoke exposure levels that exceeded WHO and US guidance, but smoke-free vehicle legislation was effective at reducing second-hand smoke exposure in cars. However, another study reported no reduction in self-reported respiratory symptoms among children aged 8–15 years after the introduction of smoke-free vehicle legislation in England.

Added value of this study

This country-wide study of admissions to hospital over a 19-year period confirmed no effect of smoke-free vehicle legislation on older children but showed a significant reduction in admissions to hospital for asthma among children younger than 5 years, accounting for the underlying trend in monthly hospital admissions for asthma and previous interventions designed to reduce second-hand smoke exposure.

Implications of all the available evidence

Preschool children are at the greatest risk of exposure to parental smoking. Legislation prohibiting smoking in vehicles is effective at reducing exposure to second-hand smoke and, in preschool children, might be effective at reducing their risk of severe asthma requiring admission to hospital. Countries without laws that prohibit smoking in cars when children are present should be encouraged to adopt such legislation.

childhood admissions to hospital for asthma[6] that have persisted over time.[7] In March, 2014, a Scottish mass-media health education campaign, Take it Right Outside (TiRO), reinforced the importance of not smoking in homes in which children resided.[7] Following this campaign, there have been further reductions in admissions to hospital for asthma among children younger than 5 years.[7]

In December, 2016, the Smoking Prohibition (Children in Motor Vehicles) (Scotland) Act made it illegal to smoke in vehicles containing someone below 18 years of age. In this study, we reanalysed the data used for the evaluation of the TiRO campaign[7] to determine whether the subsequent introduction of smoke-free vehicle legislation resulted in changes in incidence of childhood hospital admissions for asthma, over and above those achieved by the previous interventions, and whether any impact varied by age or level of socioeconomic deprivation.

Methods

Study design

We used an interrupted time-series analysis to quantify changes in Scotland-wide hospital admissions for childhood asthma over a 19-year period following the 2016 introduction of smoke-free vehicle legislation, also taking into account the 2006 introduction of legislation against smoking in public spaces and the 2014 TiRO public health initiative. The Scottish Morbidity Record 01 (SMR01) records information on every hospital admission in Scotland including age, sex, postcode of residence, date and urgency of admission, and reason for admission, coded using the International Classification of Diseases version 10 (ICD-10). Inclusion in this study was restricted to all emergency admissions to hospital for asthma of patients younger than 16 years of age, occurring between Jan 1, 2000, and Dec 31, 2018, inclusive. Area deprivation was measured using the Scottish Index of Multiple Deprivation (SIMD), which ranked 6976 areas of residence (total population 5·2 million) in 2016 on the basis of aggregated data across the following seven domains: income, employment, health, education, housing, access (in terms of mean time) to basic services, and crime.[8] The postcodes of residence of children included in the study were used to categorise them into general population quintiles of the SIMD, from 1 (most deprived) to 5 (least deprived). Area deprivation was assumed to be similar to 2016 levels across the study period. Approval for the study was provided by the Scottish Public Benefit and Privacy Panel for Health and Social Care (reference 1819-0251). This study was a secondary analysis of anonymised, individual-level administrative data held in the Scottish National Safe Haven (a secure database from which data cannot be removed without permission). Therefore, UK National Health Service ethics approval was not required and the researchers were neither able nor required to obtain individual participant consent.

See Online for appendix

Outcomes

The primary outcome of this study was monthly incidence of emergency hospital admissions for asthma, defined as an ICD-10 code of J45.0, J45.9 or J46X (full descriptions of the codes are provided in the appendix). To understand the effects of the 2016 smoke-free vehicle legislation on admissions over and above the effects of other public health interventions, our study included two earlier known change points as follows: the 2006 legislation banning smoking in public places[6] and the 2014 TiRO mass-media campaign advising against smoking in homes containing children.[7]

To test for unknown or unmeasured changes that coincided with the introduction of smoke-free vehicle legislation, we included admissions data for gastroenteritis as a control condition. Emergency admissions to hospital for gastroenteritis among children younger than 16 years were ascertained from the following ICD-10 codes: A08.0, A08.1, A08.2, A08.3, A08.4, A09.0, A09.9, A09X, and K52.9 (appendix). We also explored the effect of the smoke-free vehicle legislation on other respiratory conditions included in the study of the TiRO campaign[7] in post-hoc analyses; these conditions were defined as follows: lower respiratory tract infections (J12.0, J12.2, J12.8, J12.9, J13.X, J14.X, J15.1, J15.2, J15.4, J15.7-9, J18.0, J18.1, J18.1D, J18.8, J18.9, and J22.X), croup (J05.0), acute otitis media (H65.0, H66.4, and H66.9), and bronchiolitis (J21.0, J21.8, J21.9, and J12.1; appendix).

Additionally, we assessed whether outcomes were affected by age (<5 years and 5–15 years) and SIMD quintile. To comply with the data protection requirement for data minimisation, the data controllers (the Information Services Division of the Scottish Government) provided SIMD data only for children in quintiles 1, 3, and 5 who were admitted to hospital for asthma; SIMD data for individuals in SIMD quintiles 2 and 4 and breakdowns of SIMD data for the control condition of gastroenteritis and for respiratory conditions other than asthma were not provided to us by the data controllers. Therefore, subgroup analyses by SIMD subgroup were restricted to three quintiles and undertaken for the primary outcome (asthma admissions) only.

Statistical analysis

For each month, from January, 2000, to December, 2018, we determined monthly emergency hospital admissions for asthma per 100 000 children younger than 16 years in Scotland from SMR01 records. We used mid-year population counts, obtained from the National Records of Scotland,[9] to estimate monthly population (age <16 years) from 2000 to 2018 via linear interpolation and extrapolation. The monthly hospital admission counts were combined with monthly population counts to derive monthly incidence of admissions to hospital for asthma per 100 000 children. These incidences were then adjusted for unequal month length using the following formula: $(\text{count} \times 100\,000 \times 365 \cdot 25) / (\text{population} \times 12 \times \text{days in month})$, and then log transformed.

We used time-series regression with seasonal autoregressive integrated moving average (SARIMA) errors and an interrupted time-series design to estimate the effect of the legislation on admissions per 100 000 children over time. We reran the model with stratification by age (<5 years and 5–15 years) and by SIMD quintile (SIMD 1, 3, and 5) for asthma admissions. The model examined change after the 2016 introduction of smoke-free vehicle legislation relative to the underlying trend, and also included the 2006 smoke-free public places legislation[6] and the 2014 TiRO campaign.[7] As there were no indications of step changes around the time that smoke-free vehicle legislation was introduced, the model tested for potential changes in the slope with reference to the underlying trend only. Underlying trend values and trend values after the interventions (relative to the underlying trend) were expressed as the mean percentage change in monthly admissions. We also applied the estimated models to the underlying absolute rates to determine the cumulative reductions.

Initial specification of the SARIMA error models was derived from plots of the autocorrelation and partial-autocorrelation functions with the choice of intervention model informed by graphs of the monthly admission rates for each outcome over time. The errors model was then estimated jointly with the intervention model via maximum likelihood and the residuals inspected for evidence of departure from a white-noise series using the Ljung-Box test.[10] Where model residuals showed evidence of remaining autocorrelation, the models were re-estimated until their residuals conformed to a white-noise process.

Time series often exhibit evidence of outliers, which need to be modelled appropriately for efficient estimation of intervention effects. We extracted the residuals from each model and then applied the isoutlier function in MATLAB version 9.1 update 1 to obtain a list of identified outliers using Grubbs' method,[11] the generalised extreme Studentized method,[12] a sliding window mean, and scaled median. These outliers were incorporated into the model and the residuals tested for white noise. Coefficients were then converted into percentages using the following transformation: $100 \times (\exp(\beta) - 1)$. Initial data cleaning was done using SPSS 25 and all statistical analyses were done using the econometrics toolbox from MATLAB. A p value of less than 0·05 was assumed to indicate significance.

As with asthma, for the analysis of the control condition of gastroenteritis, and for the post-hoc analysis of respiratory conditions other than asthma, admissions were combined with population data to derive monthly incidence data and the interrupted time-series model was used to investigate whether any change to the underlying trend occurred over time after December, 2016. We also reran the model for these conditions in one or both age groups if significant effects were identified for the primary outcome in those age groups.

Role of the funding source

There was no funding source for this study.

Results

Over the 19-year study period (Jan 1, 2000, to Dec 31, 2018), there were 32 342 emergency admissions to hospital for asthma among children younger than 16 years; of these, 13 954 (43%) were among children younger than 5 years and 18 388 (57%) were among children aged 5–15 years

	Asthma (n=32 342)	Lower respiratory tract infection (n=32 632)	Croup (n=18 663)	Acute otitis media (n=4489)	Bronchiolitis (n=50 805)	Gastroenteritis (n=58 126)
Age (years)	5·8 (3·5–9·7)	3·0 (1·5–5·8)	1·9 (1·1–3·4)	1·8 (1·1–3·6)	0·4 (0·2–0·8)	1·7 (0·8–4·0)
<5	13 954 (43%)	23 141 (71%)	16 328 (87%)	3836 (85%)	50 675 (>99%)	46 835 (81%)
5–15	18 388 (57%)	9491 (29%)	2335 (13%)	653 (15%)	130 (<1%)	11 291 (19%)
Sex						
Male	20 147 (62%)	17 469 (54%)	13 080 (70%)	2634 (59%)	30 366 (60%)	30 744 (53%)
Female	12 195 (38%)	15 163 (46%)	5583 (30%)	1855 (41%)	20 439 (40%)	27 382 (47%)
Area deprivation quintile*						
SIMD 1 (most deprived)	10 179 (31%)	..	..	..	..	..
SIMD 3	5775 (18%)	..	..	..	..	..
SIMD 5 (least deprived)	4046 (13%)	..	..	..	..	..

Data are median (IQR) or n (%). SIMD=Scottish Index of Multiple Deprivation. *SIMD data were available for asthma admissions only.

Table 1: **Characteristics of individuals younger than 16 years admitted to hospital as an emergency in Scotland with asthma, other respiratory conditions, or gastroenteritis between 2000 and 2018**

(table 1). 10 179 (31%) of the children admitted to hospital lived in areas in the most deprived quintile, 5775 (18%) in the middle quintile, and 4046 (13%) in the most affluent quintile (table 1).

After the introduction of smoke-free vehicle legislation, there was a decline in the slope for monthly emergency admissions to hospital for asthma among children (–1·21%, 95% CI –2·64 to 0·23), but this was not statistically significant (table 2). There was also no significant change among children aged 5–15 years, but children younger than 5 years had a significant decline in the slope for monthly emergency admissions to hospital for asthma (–1·49%, –2·69 to –0·27) after the introduction of smoke-free vehicle legislation (figure, table 2), over and above the underlying trend for childhood asthma admissions in this age group. Applying the estimated models to the underlying absolute rates produced a cumulative reduction of 12 admissions to hospital for asthma (95% CI 2 to 21) among children younger than 5 years over the 24 months after the introduction of smoke-free vehicle legislation, equivalent to a mean of six admissions to hospital (95% CI 1 to 11) avoided per year over and above the underlying trend.

We observed differences by area deprivation. The relative reduction in monthly admissions to hospital was greatest among the most affluent quintile, and smaller but still significant in the middle quintile, but there was no significant change in the most deprived quintile (table 2). However, the absolute reductions across quintiles were similar. Among the most deprived quintile, incidence fell from a mean of 0·87 admissions to hospital per 100 000 population per month over the study period before the legislation to a mean of 0·72 admissions to hospital per 100 000 population per month over the months following the introduction of the legislation, and among the least deprived quintile from 0·32 per 100 000 population per month to 0·21 per 100 000 population per month, with an absolute reduction of 0·15 per 100 000 per month in both groups (95% CI 0·10–0·21 in the most deprived quintile and 0·11–0·18 in the least deprived quintile).

Over the same study period, there were 58 126 admissions to hospital for gastroenteritis (table 3). 46 835 (81%) of 58 126 admissions were in children younger than 5 years and 11 291 (19%) were in children aged 5–15 years. After the introduction of legislation for smoke-free vehicles there was no significant change in monthly admissions to hospital for gastroenteritis in children overall (0·05%, 95% CI –1·38 to 1·50) or in children younger than 5 years (0·12%, –1·49 to 1·75). There were also no significant changes in other respiratory conditions either overall or among children younger than 5 years (table 3). For these conditions, we focused the age analyses on children younger than 5 years as the significant effect for the primary outcome was restricted to this group.

Discussion

In Scotland, admissions to hospital for asthma among preschool children fell significantly over the 2 years after the introduction of smoke-free vehicle legislation, but there was no benefit among the overall group or for children aged 5–15 years. The reduction in preschool children was over and above underlying trends and any effects of previous interventions such as smoke-free public place legislation and the national mass-media TiRO health education campaign. The effect on admissions was specific to asthma and did not occur for the control condition, gastroenteritis, or for other respiratory conditions.

Exposure to second-hand smoke is particularly injurious to children because of their higher respiratory rate,[13] and increases their risk of asthma[1] and asthma exacerbations.[2] Globally, an estimated 169 000 deaths in childhood per year are attributable to exposure to second-hand smoke.[14] Although childhood asthma hospital admissions were shown to decline after the introduction of smoke-free public place legislation in Scotland,[6] England,[15] and the USA,[16] such legislation

	All children		By age group				By deprivation category					
			<5 years		5–15 years		SIMD 1 (most deprived)		SIMD 3		SIMD 5 (least deprived)	
	Coefficient (95% CI)	p value	Coefficient (95% CI)	p value	Coefficient (95% CI)	p value	Coefficient (95% CI)	p value	Coefficient (95% CI)	p value	Coefficient (95% CI)	p value
Underlying trend	0·01% (−0·29 to 0·31)	0·95	−0·28% (−0·70 to 0·15)	0·19	0·50% (0·25 to 0·76)	<0·0001	0·13% (−0·31 to 0·57)	0·57	0·19% (−0·42 to 0·80)	0·55	−0·06% (−0·75 to 0·65)	0·88
Smoke-free public place legislation (2006)	−0·25% (−0·74 to 0·23)	0·31	−0·25% (−0·71 to 0·22)	0·29	−0·61% (−0·92 to −0·30)	<0·0001	−0·26% (−0·75 to 0·22)	0·29	−0·59% (−1·18 to 0·01)	0·052	−0·30% (−1·34 to 0·74)	0·57
TiRO campaign (2014)	0·22% (−0·63 to 1·09)	0·61	0·11% (−0·52 to 0·74)	0·73	0·22% (−0·26 to 0·70)	0·36	−0·25% (−0·99 to 0·49)	0·50	0·53% (−0·26 to 1·32)	0·19	0·30% (−1·32 to 1·95)	0·72
Smoke-free vehicle legislation (2016)	−1·21% (−2·64 to 0·23)	0·10	−1·49% (−2·69 to −0·27)	0·016	−0·91% (−2·18 to 0·38)	0·16	0·14% (−1·42 to 1·72)	0·86	−1·72% (−3·23 to −0·18)	0·028	−2·27% (−4·41 to −0·07)	0·042

Data are mean (95% CI); p value. Underlying trend values show the mean percentage change in monthly admissions; trend values after the interventions show mean percentage change in monthly admissions relative to the underlying trend. SIMD=Scottish Index of Multiple Deprivation. TiRO=Take it Right Outside.

Table 2: **Interrupted time series analyses of emergency admissions to hospital for asthma overall and stratified by age and social deprivation**

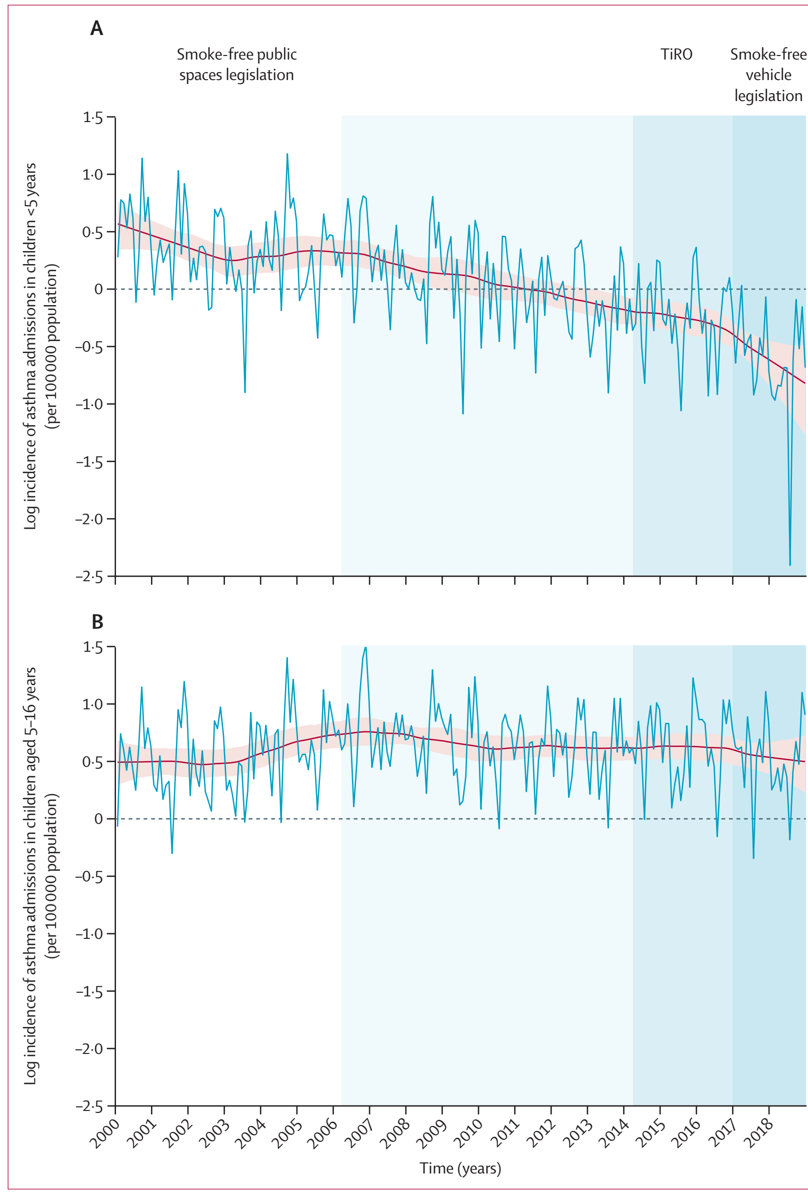

Figure: **Monthly incidence of emergency asthma admissions to hospital among children in Scotland aged <5 years (A) and 5–15 years (B)**

The solid line indicates the mean log-transformed standardised number of admissions and the dotted lines indicate the bootstrapped 95% CIs. Different coloured sections show the introduction of the smoke-free public spaces legislation in March, 2006, the TiRO public health initiative in March, 2014, and the smoke-free vehicle legislation in Dec, 2016. TiRO=Take it Right Outside.

does not directly address the primary locations in which children are exposed. In Wales, smoke-free public place legislation was introduced in 2008. Before the legislation, 37% of children aged 10–11 years reported that smoking was allowed in their homes and 18% reported that it was allowed in their family car.[17] In 2014, these figures had fallen to 26% and 9%, respectively. However, among children with a parent who smoked, 50% were still being exposed in their homes and 20% in their family cars.

	All children		<5 years	
	Coefficient (95% CI)	p value	Coefficient (95% CI)	p value
Gastroenteritis				
Underlying trend	0·20% (–0·19 to 0·59)	0·32	0·17% (–0·27 to 0·62)	0·44
Smoke-free public place legislation (2006)	–0·36% (–0·80 to 0·08)	0·11	–0·36% (–0·87 to 0·16)	0·17
TiRO campaign (2014)	0·21% (–0·52 to 0·95)	0·57	–0·01% (–0·85 to 0·83)	0·97
Smoke-free vehicle legislation (2016)	0·05% (–1·38 to 1·50)	0·94	0·12% (–1·49 to 1·75)	0·89
Lower respiratory tract infections				
Underlying trend	0·51% (–0·98 to 2·02)	0·51	0·61% (–0·81 to 2·06)	0·40
Smoke-free public place legislation (2006)	–0·43% (–1·01 to 0·14)	0·51	–0·35% (–0·93 to 0·23)	0·24
TiRO campaign (2014)	0·09% (–0·67 to 0·87)	0·81	–0·43% (–1·22 to 0·36)	0·28
Smoke-free vehicle legislation (2016)	–0·80% (–2·26 to 0·68)	0·28	0·21% (–1·34 to 1·78)	0·79
Croup				
Underlying trend	0·46% (0·10 to 0·81)	0·012	0·45% (0·05 to 0·85)	0·028
Smoke-free public place legislation (2006)	–0·37% (–0·70 to –0·04)	0·028	–0·34% (–0·70 to 0·02)	0·064
TiRO campaign (2014)	–0·21% (–0·84 to 0·43)	0·52	–0·20% (–0·81 to 0·42)	0·53
Smoke-free vehicle legislation (2016)	1·06% (–0·84 to 2·99)	0·27	0·68% (–1·18 to 2·59)	0·47
Acute otitis media				
Underlying trend	0·39% (–0·09 to 0·87)	0·11	0·35% (–0·20 to 0·90)	0·21
Smoke-free public place legislation (2006)	–0·40% (–1·08 to 0·29)	0·26	–0·33% (–1·10 to 0·45)	0·40
TiRO campaign (2014)	0·65% (–0·55 to 1·86)	0·29	0·52% (–0·79 to 1·84)	0·44
Smoke-free vehicle legislation (2016)	–0·99% (–3·86 to 1·95)	0·50	–1·45% (–4·43 to 1·63)	0·35
Bronchiolitis				
Underlying trend	0·40% (–0·19 to 1·00)	0·18	0·47% (0·18 to 0·76)	<0·0001
Smoke-free public place legislation (2006)	0·35% (–0·45 to 1·16)	0·39	0·33% (–0·13 to 0·79)	0·16
TiRO campaign (2014)	0·43% (–0·88 to 1·75)	0·52	0·36% (–0·71 to 1·46)	0·51
Smoke-free vehicle legislation (2016)	–1·22% (–3·81 to 1·44)	0·36	–1·45% (–3·81 to 0·97)	0·24

Data are mean (95% CI); p value. Underlying trend values show the mean percentage change in monthly admissions; trend values after the interventions show mean percentage change in monthly admissions relative to the underlying trend. Age analyses for gastroenteritis and other respiratory conditions focused on children younger than 5 years as the significant effect for the primary outcome was restricted to this group. TiRO=Take it Right Outside.

Table 3: **Interrupted time series analyses of emergency admissions to hospital for gastroenteritis and other respiratory conditions for all children and for children younger than 5 years**

The principal source of second-hand smoke exposure among young children is parental smoking. Smoking in cars is an important contributor to second-hand smoke exposure. Among non-smoking adults, second-hand smoke exposure in the family car leads to higher cotinine concentrations than does second-hand exposure in the home, workplace, or public places.[18] Children exposed to second-hand smoke in cars are more likely to develop wheeze and have poorer lung function than children exposed to second-hand smoke at home, as well as unexposed children.[19] In an experiment that replicated 63 normal car journeys taken by smokers, averaging 27 min duration, all journeys produced fine particulate matter ($PM_{2·5}$) concentrations that exceeded WHO indoor air-quality guidance, even when car windows were opened.[20] A systematic review of 12 studies reported that smoking in cars can lead to $PM_{2·5}$ concentrations that substantially exceed the US Environmental Protection Agency's daily and annual standards for fine particulate air pollution.[21] The authors of this review concluded that the only way to protect children was via legislation prohibiting smoking in cars in which they are travelling.[21]

Studies have shown smoke-free vehicle legislation to be effective at reducing exposure to second-hand smoke in cars.[22–25] In California, there was a 12% reduction in students reporting exposure in cars after the state's introduction of smoke-free vehicle legislation, a reduction not seen in other US states and against an underlying decline of 1% per annum.[23] In a telephone survey of adults living in Maine, USA, the proportion of people who reported having smoke-free vehicles increased from 74·9% to 78·8% after the introduction of state smoke-free vehicle legislation.[24] Furthermore, the proportion of people reporting smoke-free homes also increased from 79·9% to 83·1%, suggesting that smoke-free vehicle legislation might produce more wide-reaching behavioural changes by changing social norms.[24] This observation is consistent with the finding that smoke-free public place legislation in Scotland was followed by an increase in voluntary restrictions on smoking in homes containing children.[5] In England, the proportion of children aged 13–15 years who reported regular exposure to second-hand smoke in cars fell from 6·3% and 5·9% in the 2 years preceding smoke-free vehicle legislation to 1·6% in the year after.[25] No studies have directly compared exposure of children to second-hand smoke in vehicles before and after the Scottish legislation. However, separate studies have reported that 7% of children were exposed over a single week in 2006, whereas less than 1% of all children were exposed in 2019.[26]

In our study, we found no benefit of smoke-free vehicle legislation among children older than 5 years. This result is consistent with findings in England, where children aged 8–15 years reported no reduction in respiratory symptoms or asthma after the introduction of smoke-free vehicle legislation in October, 2015.[27] Our study showed that the reduction in asthma admissions to hospital was specific to preschool children. This finding is plausible, since exposure to parental smoke is higher among preschool children, who spend a greater proportion of their time with their parents. Among children whose parents smoke, cotinine concentrations are higher among preschool children[28] than among school-aged children.[5]

Our findings suggest possible widening of health inequalities, whereby the relative reduction in childhood asthma hospital admissions was greater among those living in the most affluent areas and not observed among those living in the most deprived areas. However, since the absolute reduction in incidence was similar in both these groups, the differences in relative reduction might simply reflect the lower pre-legislation incidence in the affluent subgroup. Our findings relating to smoke-free vehicle legislation contrast with our previous findings relating to smoke-free public place legislation, for which the relative reduction in childhood asthma hospital admissions was only apparent in the most deprived group.[7] Smoke-free public place legislation was supported by systematic monitoring and enforcement deterring breaches across all socioeconomic groups. By contrast, absence of enforcement of smoke-free vehicle legislation, as evidenced by no judicial cases, has resulted in reliance on voluntary adherence. If such adherence is lower in deprived areas, this could explain why the vehicle legislation has been less effective in deprived populations compared with more affluent populations. In the 2019 Scottish Health Survey, less than 1% of children in the three most affluent quintiles were exposed to second-hand smoke in vehicles compared with 1% of children in the two most deprived quintiles,[26] showing that breaches of the legislation might be more likely in deprived communities. The difference in relative reduction of asthma admissions to hospital might also reflect higher rates of car ownership in more affluent areas. People in lower-income households are more likely to travel by bus, whereas people in higher-income households are more likely to drive or travel by train.[29] Therefore, the observed differences in effect by level of deprivation might be due to multiple factors including differences in baseline absolute risk, compliance, and the contribution of vehicles to overall second-hand smoke exposure.

We did a quasi-experimental study using routine health data. The study covered all admissions to hospital across the whole of Scotland, thereby avoiding selection or recruitment bias. The study population was sufficiently large to support subgroup analyses by age and area deprivation. In our model, we were able to account for both underlying trends and two other interventions previously reported to have affected the outcome of interest: smoke-free public place legislation and a mass-media health education campaign, TiRO. However, as with any natural experiment, it is impossible to be certain that no unknown factors influenced the outcome over the study period.

In this study, we reanalysed data used in the previous evaluation of TiRO,[7] adding implementation of smoke-free vehicle legislation as an additional change point. Including additional trends means that the SARIMA errors might explain earlier trends not previously explained or the previous trends might be absorbed by serial correlation terms. Seasonality can also trend over time and so should also be modelled out of the data. Compared with the previous study,[6,7] we still found an underlying increase in asthma admissions to hospital among older children (aged 5–15 years), the previously observed fall in admissions to hospital after the introduction of smoke-free public place legislation among both age groups[6,7] was now specific to older children, and the reduction in admissions to hospital among younger children after TiRO[7] was no longer observed. Therefore, it is possible that the effect of TiRO previously reported was, in fact, due to the subsequent introduction of smoke-free vehicle legislation.[7]

Our primary outcome was restricted to admissions to hospital for asthma; exposure to second-hand smoke is associated with more severe and more frequent asthma exacerbations.[2] We did not have data on less severe events managed in the community; therefore, any systematic error will have been in the direction of underestimating the overall effect of the smoke-free vehicle legislation. Avoiding six hospital admissions per year might appear to be a small effect but, underlying this, there could be a much larger number of children who avoided less severe exacerbations that did not require admission to hospital but who nonetheless benefited by avoiding symptoms, anxiety, school absence, parental time off work, and health-care costs. Asthma diagnosis is more likely to be uncertain in children younger than 5 years. Any effect this might have is likely to result in underestimation of the effect in this age group.

As with any observational study, the finding of an association does not prove causation. However, our findings satisfy many of the Bradford Hill criteria for causation.[30] A causal effect of the smoke-free vehicle legislation on childhood asthma hospital admissions is plausible, given existing evidence of an association between exposure to second-hand smoke in cars and childhood asthma and the effectiveness of legislation at reducing exposure. The decline in admissions to hospital occurred after the introduction of the legislation, showing temporality, and was specific to asthma (not occurring for gastroenteritis) and to preschool children, who spend more time with their parents.

In conclusion, after the introduction of smoke-free vehicle legislation in Scotland, admissions to hospital for asthma among preschool children have fallen significantly. Countries without similar legislation should be encouraged to adopt regulations that prohibit smoking in vehicles containing children.

Contributors

JPP, DFM, and SWT conceived the original idea for the study. JPP, SWT, and SES reviewed the literature. SWT obtained the data and DFM analysed the data. All authors interpreted the results. JPP drafted the manuscript and DFM, SWT, SES, and SD reviewed and edited the manuscript. DFM and SWT accessed and verified the underlying data. All authors had full access to all the data in the study and the final responsibility for the decision to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

This study used an extract of linked pre-existing routinely collected data. We are not the data controllers for the data used and, under the terms of our data sharing agreement with the data controller, we are not permitted to pass the data onto a third party. Anyone wishing to obtain these, or similar, data should apply directly to the electronic Data Research and Innovation Service (eDRIS) via phs.edris@phs.scot.

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