Associations between a smoke-free homes intervention and childhood admissions to hospital in Scotland: an interrupted time-series analysis of whole-population data

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Summary

Background Many children are exposed to second-hand smoke in the home and are at increased risk of asthma and other respiratory conditions. In Scotland, a public health mass-media campaign was launched on March 24, 2014, called Take it Right Outside (TiRO), with a focus on reducing the exposure of children to domestic second-hand smoke. In this study, our aim was to establish whether the TiRO campaign was followed by a decrease in hospital admissions for childhood asthma and other respiratory conditions related to second-hand smoke exposure across Scotland.

Methods For an interrupted time-series analysis, data were obtained on all hospital admissions in Scotland between 2000 and 2018 for children aged younger than 16 years. We studied changes in the monthly incidence of admissions for conditions potentially related to second-hand smoke exposure (asthma, lower respiratory tract infection, bronchiolitis, croup, and acute otitis media) per 1000 children following the 2014 TiRO campaign, while considering national legislation banning smoking in public spaces from 2006. We considered asthma to be the primary condition related to second-hand smoke exposure, with monthly asthma admissions as the primary outcome. Gastroenteritis was included as a control condition. The analysis of asthma admissions considered subgroups stratified by age and area quintile of the Scottish Index of Multiple Deprivations (SIMD).

Findings 740 055 hospital admissions were recorded for children. 138 931 (18·8%) admissions were for respiratory conditions potentially related to second-hand smoke exposure, of which 32 342 (23·3%) were for asthma. After TiRO in 2014, we identified a decrease relative to the underlying trend in the slope of admissions for asthma (–0·48% [–0·85 to –0·12], p=0·0096) in younger children (age <5 years), but not in older children (age 5–15 years). Asthma admissions did not change after TiRO among children 0–15 years of age when data were analysed according to area deprivation quintile. Following the 2006 legislation, independent of TiRO, asthma admissions decreased in both younger children (–0·36% [–0·67 to –0·05], p=0·021) and older children (–0·68% [–1·00 to –0·36], p<0·0001), and in children from the most deprived (SIMD 1; –0·49% [–0·87 to –0·11], p=0·011) and intermediate deprived (SIMD 3; –0·70% [–1·17 to –0·23], p=0·0043) area quintiles, but not in those from the least deprived (SIMD 5) area quintile.

Interpretation Our findings suggest that smoke-free home interventions could be an important tool to reduce asthma admissions in young children, and that smoke-free public space legislation might improve child health for many years, especially in the most deprived communities.

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Introduction

Children exposed to second-hand smoke are at increased risk of many respiratory conditions including asthma, lower respiratory tract infection, croup, bronchiolitis, and otitis media.[1] Exposure to second-hand smoke is preventable, and smoke-free legislation that prohibits smoking in wholly or partly enclosed public spaces has been associated with reduced childhood morbidity of respiratory conditions.[2]

The WHO Framework Convention on Tobacco Control, Article 8, indicates the importance of "providing for protection from exposure to tobacco smoke in indoor workplaces, public transport, indoor public places and, as appropriate, other public places",[3] but the smoke-free legislation implemented in many countries does not extend to private areas. Thus, children whose parents and carers smoke are exposed to second-hand smoke at home. Evidence that smoke-free legislation for public spaces does not directly protect children from second-hand smoke was evident in Scotland immediately after legislation was introduced on March 26, 2006: exposure of children to second-hand smoke in other people's homes, restaurants, and on public transport was significantly reduced, but not in the children's own homes, according to national cross-sectional surveys between January, 2006, and January, 2007.[4]

Research in context

Evidence before this study

We did a literature search in PubMed on July 16, 2020, for scientific papers published from database inception that examined the relationship between smoke-free home initiatives and admissions of children to hospital with asthma. The search terms used were "asthma", "child", "respiratory", "second-hand smoke", "smoke free", and "hospital admissions", with no limits applied to publication dates or language. Further studies were identified from the reference lists of the preliminary search results.

Our search identified a large number of studies. Many papers described second-hand smoke exposure as a risk factor for children being admitted to hospital. We identified randomised controlled trials in which smoke-free home interventions were delivered to individual homes. We found no studies that evaluated child health outcomes following a smoke-free homes intervention delivered on a whole-population basis.

Added value of this study

We studied all hospital admissions among children (age <16 years) in Scotland between 2000 and 2018. We found that after the launch of the Take it Right Outside (TiRO) public health initiative in 2014, which aimed to reduce domestic exposure of children to second-hand smoke, there was a decrease in asthma admissions among children aged younger than 5 years relative to the underlying trend.

We also found that, independent of TiRO, 2006 legislation for smoke-free public spaces was associated with reduced asthma admissions in children of all ages and among those in the quintile of greatest deprivation.

Implications of the available evidence

A public health mass media campaign to reduce the exposure of children to second-hand smoke within their homes was associated with reduced childhood asthma in families with younger children. Additionally, asthma admissions in children continued to decrease up to more than 10 years after the introduction of smoke-free public spaces.

In Scotland, a public health mass media campaign with a focus on reducing exposure of children to second-hand smoke in the home, called Take it Right Outside (TiRO) was launched on March 24, 2014. TiRO aimed to reduce the exposure of children to domestic second-hand smoke. TiRO was developed by a multidisciplinary group of health practitioners and tobacco control specialists, and was supported by research evidence showing that second-hand smoke exposure can continue for up to 5 h after a cigarette has been extinguished in the home.[5] The campaign involved advertising across television, radio, online, and print platforms, and a series of events in shopping centres. The aim was to target parents who smoke at home and promote a change in their smoking behaviour to create a smoke-free home. TiRO did not have an implicit smoking cessation message but instead offered parents practical advice on how to take smoking outside the home.

For more on the **TiRO campaign** see https://www.nhsinform.scot/campaigns/take-it-right-outside

For the **SIMD data** see https://www.gov.scot/collections/scottish-index-of-multiple-deprivation-2020

Following TiRO, the 2018 Scottish Health Survey found that the proportion of children in Scotland reported by parents or carers to be exposed to second-hand smoke in their home decreased by half, from 12% in 2012 to 6% in 2015, and this reduction was maintained in 2018.[6] The only other national smoke-free home initiative that we are aware of involved a smoke-free home pledge approach in the USA in 2001.[7] UK regional smoke free-home programmes exist[8,9] but the effect of TiRO and other smoke-free home initiatives on childhood health outcomes has not been evaluated.

In this study, we sought to assess whether TiRO was associated with a decrease in the incidence of hospital admissions in children with respiratory conditions known to be associated with second-hand smoke exposure, with a focus on admissions for asthma. We subsequently considered whether trends in asthma admissions differed between subgroups stratified by age and area-based deprivation.

Methods

Study design

We used an interrupted time-series analysis to quantify changes in monthly hospital admissions following the 2006 legislation against smoking in public spaces, and any additional change after the 2014 TiRO public health initiative. Details of all admissions to hospitals in Scotland between Jan 1, 2000, and Dec 31, 2018, for children aged younger than 16 years were provided by the Information Services Division of the Scottish Government. For each admission, the child's age, sex, area deprivation (Scottish Index of Multiple Deprivation [SIMD]), and main diagnosis, and the month and year of admission were obtained. SIMD ranked 6976 individual geographical areas across Scotland (total population 5·2 million) in 2016 by the domains: income, employment, health, education, housing, access (in terms of average time to basic services), and crime.[10] Area deprivation was assumed to be similar to 2016 levels across the study period. We included in our analysis all admissions for which the main diagnosis was asthma. In addition to asthma, we considered other diagnoses known to be associated with second-hand smoke exposure (ie, lower respiratory tract infection, bronchiolitis, croup, and acute otitis media).[1] Additionally, gastroenteritis was included as a non-respiratory condition that, although weakly related to second-hand smoke exposure,[11] is not likely to be causally related to second-hand smoke exposure and for which we expected no change after TiRO. Admission data were held in the Scottish National Safe Haven (a secure database from which data cannot be removed without permission). Approval for the study was provided by the Public Benefit and Privacy Panel for Health and Social Care (reference 1819-0251).

Disease definitions

Respiratory diseases were defined with International Classification of Diseases-10 coding, for asthma (J45.0, J45.9, and J46X), bronchiolitis (J21.0, J21.8, J21.9, and J12.1), croup (J05.0), lower respiratory tract infection (J12.0, J12.2, J12.8, J12.9, J13X, J14X, J15.1, J15.2, J15.4, J15.7, J15.8, J15.9, J18.0, J18.1, J18.1D, J18.8, J18.9, and J22X), acute otitis media (H65.0, H66.9, and H66.4), and gastroenteritis (A08.0, A08.1, A08.2, A08.3, A08.4, A09.0, A09.9, A09X, and K52.9). Full descriptions of the codes are provided in the appendix (p 1).

Outcomes

Our primary outcome was asthma admissions, as a commonly reported outcome in evaluations of the effects of smoke-free legislation on child health.[12–14] We also explored whether the effect of the 2006 legislation on admissions of children with conditions related to second-hand smoke exposure had been maintained over 12 years of follow-up. Furthermore, we sought to identify whether any decrease in asthma admissions was greatest among children who were more likely to be exposed to second-hand smoke (ie, in those aged <5 years who spend long periods at home *vs* those aged 5–15 years; and in those who live in the quintile of communities with greatest deprivation [SIMD 1] *vs* those who live in the intermediate [SIMD 3] and least deprived [SIMD 5] quintiles). We restricted these subgroup analyses to our primary outcome (asthma admissions) a priori in recognition of the risk for false-negative results due to the small sample size and for false-positive results due to multiple testing.[15] For data minimisation reasons, only asthma admission data were released by the electronic Data Research and Innovation Service of the Information Services Division of the Scottish Government for the analysis of subgroups.

Statistical analysis

For each month, admissions per 1000 children (<16 years) in Scotland were determined. We obtained annual midyear counts for the national child population (age <16 years) for 2000–18 from the National Records of Scotland and estimated monthly populations from January, 2000, to December, 2018, via linear interpolation and extrapolation. Monthly admissions for each respiratory condition per 1000 children were then adjusted for unequal month length and converted by log transformation into a monthly admission rate per 100 000 children with the equation:[16]

$$\frac{\ln(\text{count} \times 1000 \times 365 \cdot 25)}{\text{population} \times 12 \times \text{days in month}}$$

We used regression with seasonal autoregressive integrated moving average (SARIMA) errors[17] and an interrupted time-series design to estimate the effects of the 2006 legislation and the 2014 TiRO initiative on admissions of each condition per 1000 children, including stratification by age (<5 years and 5–15 years) and area deprivation (SIMD 1, 3, and 5) for asthma admissions. We analysed any change in trend in admissions per month, relative to the underlying trend, after the 2006 legislation (March, 2006) and 2014 TiRO initiative (March, 2014). We also analysed step-changes in trends in terms of change in incidence of admissions in the month that each strategy was introduced; in this study, we report only step-change after TiRO as the focus of our analysis. Initial specification of the SARIMA error models was derived from plots of the autocorrelation and partial-autocorrelation functions with the form of the intervention model informed from line graphs of the admission rates. The errors model was then estimated jointly with the intervention model via maximum likelihood analysis in MATLAB (version 9.7) and the residuals inspected for evidence of departure from a white noise series with the Ljung-Box test.[18] Where model residuals showed evidence of remaining autocorrelation, the models were re-estimated until their residuals conformed to a white noise process.

See **Online** for appendix

Time series often exhibit evidence of outliers, which need to be modelled appropriately for efficient estimation of intervention effects.[19] We extracted the residuals from each model and then applied the isoutlier function in MATLAB to obtain a list of potential outliers. These outliers were incorporated into the model and the residuals tested for white noise. Coefficients were then converted into percentages with the transformation $100 \times [\exp(\beta)\text{-}1]$. Confidence intervals for smoothed plots were constructed by bootstrapping of the data with replacement. 1000 bootstrap samples were constructed and the 2·5% and 97·5% percentiles of the bootstrap distribution were plotted. Initial data cleaning was done with SPSS (version 25) and all statistical analyses were done with the Econometrics Toolbox in MATLAB. A p value of less than 0·05 was assumed to indicate significance.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. ST and DM had access to the raw data. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

For the **National Records of Scotland midyear population estimates** see https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/population/population-estimates/mid-year-population-estimates

Results

During the 19-year study period, 740 055 hospital admissions were recorded for children in Scotland, including 518 341 (70·0%) among children aged younger than 5 years and 202 446 (27·4%) among children of all ages living in communities in the quintile with greatest deprivation. 138 931 (18·8%) admissions were for respiratory conditions

	All admissions*	Asthma	Bronchiolitis	Croup	Lower respiratory tract infection	Acute otitis media	Gastroenteritis
Number of admissions	740 055	32 342	50 805	18 663	32 632	4489	58 126
Median age, years	2·3 (0·8–6·2)	5·8 (3·5–9·7)	0·4 (0·2–0·8)	1·9 (1·1–3·4)	3·0 (1·5–5·8)	1·8 (1·1–3·6)	1·7 (0·8–4·0)
Male patients	411 422 (55·6%)	20 147 (62·3%)	30 366 (59·8%)	13 080 (70·1%)	17 469 (53·5%)	2634 (58·7%)	30 744 (52·9%)
Area deprivation quintile							
Most deprived (SIMD 1)	202 446 (27·4%)	10 179 (31·5%)	15 698 (30·9%)	4390 (23·5%)	7775 (23·8%)	1128 (25·1%)	15 974 (27·5%)
Intermediate deprived (SIMD 3)†	138 839 (18·8%)	5775 (17·9%)	..	..	..	..	..
Least deprived (SIMD 5)†	103 453 (14·0%)	4046 (12·5%)	..	..	..	..	..
Patients aged <5 years	518 341 (70·0%)	13 954 (43·1%)	50 675 (99·7%)	16 328 (87·5%)	23 141 (70·9%)	3836 (85·5%)	46 835 (80·6%)

Data are n, n (%), or median (IQR). SIMD=Scottish Index of Multiple Deprivation. *Including other diagnoses not specified in the table. †Only asthma data were analysed for SIMD 3 and 5.

Table 1: **Characteristics of children (<16 years) admitted to hospitals in Scotland between 2000 and 2018 by overall admissions and specific diagnoses**

	Asthma	Bronchiolitis	Croup	Lower respiratory tract infection	Acute otitis media	Gastroenteritis
Underlying trend	0·17% (–0·09 to 0·43); p=0·21	0·47% (0·04 to 0·89); p=0·031	0·30% (–0·27 to 0·88); p=0·30	0·49% (0·16 to 0·81); p=0·0032	0·40% (0·05 to 0·74); p=0·023	0·19% (–0·19 to 0·58) p=0·32
Trend after smoke-free legislation (2006)	–0·45% (–0·73 to –0·18); p=0·0012	0·30% (–0·31 to 0·92); p=0·33	–0·25% (–0·68 to 0·17); p=0·24	–0·39% (–0·72 to –0·05); p=0·024	–0·48% (–0·96 to 0·01); p=0·052	–0·31% (–0·76 to 0·14); p=0·17
Step-change after TiRO (2014)	10·13% (–1·43 to 23·04); p=0·086	1·22% (–21·44 to 30·41); p=0·93	–4·43% (–19·65 to 13·67); p=0·61	–4·30% (–15·89 to 8·89); p=0·50	21·63% (–9·38 to 63·25); p=0·19	–8·31% (–19·41 to 4·31); p=0·19
Trend after TiRO (2014)	–0·26% (–0·62 to 0·11); p=0·17	–0·07% (–0·85 to 0·71); p=0·85	0·10% (–0·34 to 0·55); p=0·65	–0·18% (–0·58 to 0·22); p=0·37	0·17% (–0·64 to 0·98); p=0·68	0·29% (–0·22 to 0·80); p=0·24

Data are mean (95% CI); p value. Underlying trend values show the mean percentage change in monthly admissions; trend values after the 2006 legislation and 2014 TiRO initiative show mean percentage change in monthly admissions relative to the underlying trend. Step-change values show the immediate change in the month the TiRO initiative was introduced. TiRO=Take it Right Outside.

Table 2: **Interrupted time-series analysis of all child admissions for conditions associated with second-hand smoke exposure or gastroenteritis**

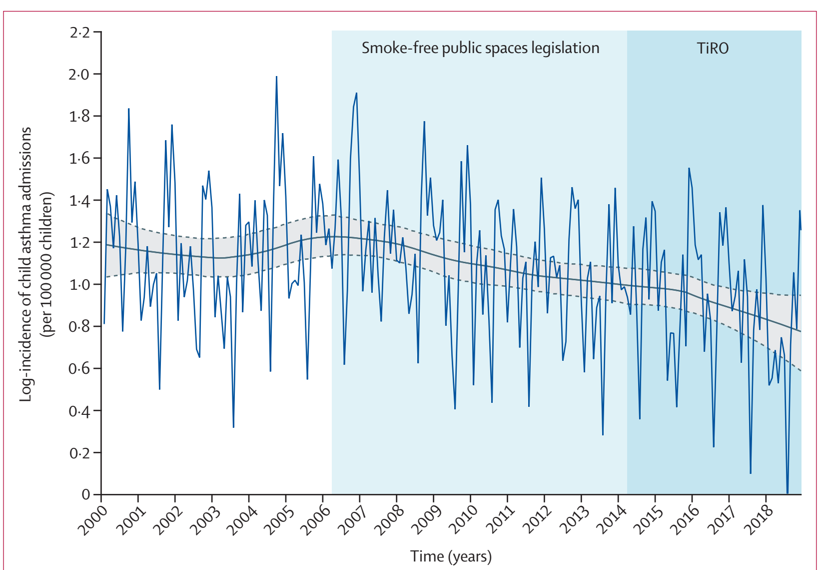

Figure 1: **Monthly hospital admissions for asthma per 100 000 children in Scotland for all children (<16 years) between Jan 1, 2000, and Dec 31, 2018**
The solid line indicates the mean log-transformed standardised number of admissions and the dotted lines indicate the bootstrapped 95% CIs. Vertical lines show the introduction of the smoke-free public spaces legislation in March, 2006, and the TiRO public health initiative in March, 2014. TiRO=Take it Right Outside.

potentially related to second-hand smoke exposure, of which 32 342 (23·3%) were for asthma. Table 1 presents the characteristics of the study population.

When all children were considered, between 2000 and 2018 we identified overall increases in the monthly number of admissions per 1000 children for bronchiolitis, lower respiratory tract infection, and acute otitis media (table 2). We observed no change in the underlying trend or step-change in admissions in the whole sample for any of the studied conditions after TiRO in 2014. In the years after the 2006 smoke-free public spaces legislation, for children aged 0–15 years we identified decreases relative to the underlying trend, and independent of TiRO, in the slopes for admissions for asthma (–0·45% [–0·73 to –0·18], p=0·0012) and lower respiratory tract infection (–0·39% [–0·72 to –0·05], p=0·024; figure 1, table 2). There were no significant changes in the slopes for admissions of other respiratory conditions or gastroenteritis after the 2006 legislation or 2014 TiRO initiative (table 2).

Between 2000 and 2018, the underlying trend in asthma admissions in younger children (age <5 years) did not change significantly, while the trend in asthma admissions increased for older children (age 5–15 years; table 3). Looking specifically at the years after TiRO (2014–18), we identified a significant decrease relative to the underlying trend in the slope of admissions for asthma in younger children (–0·48% [–0·85 to –0·12], p=0·0096) but not in older children (table 3, figure 2). Among older children, we observed a step-wise increase in asthma admissions when TiRO was launched in March, 2014 (table 3). In the years after the 2006 legislation, and independent of TiRO, there were decreases in admissions for asthma in both younger children (–0·36% [–0·67 to –0·05], p=0·021) and older children (–0·68% [–1·00 to –0·36], p<0·0001; table 3, figure 2, appendix p 2).

Monthly rates of asthma admissions did not significantly change over time among children living in the most deprived (SIMD 1), intermediate deprived (SIMD 3), and least deprived (SIMD 5) area quintiles between 2000 and 2018 (table 4). Asthma admissions did not change in any of the three deprivation categories after TiRO in 2014. The slope for asthma admissions decreased relative to the underlying trend after the 2006 legislation, independent of TiRO, for children from SIMD 1 (–0·49% [–0·87 to –0·11], p=0·011) and SIMD 3 (–0·70% [–1·17 to –0·23], p=0·0043) areas. By contrast, there was no significant change in the trend in asthma admissions among children from SIMD 5 areas after the 2006 legislation (table 4).

Discussion

This study explored the trends in child hospital admissions for asthma and other conditions related to second-hand smoke exposure in the context of the TiRO initiative in Scotland, which aimed to reduce domestic exposure of children to second-hand smoke. Our analysis also considered how admissions had changed following the national 2006 legislation banning smoking in public spaces. The first key finding was that among children aged younger than 5 years, but not in all children aged 0–15 years, the 2014 TiRO intervention was followed by a reduction in hospital admissions for asthma relative to the underlying trend. We believe this result is the first to show an association between a national smoke-free media campaign and improved childhood respiratory health outcomes. The second key finding was that in all children, admissions for asthma and lower respiratory tract infection continued to decrease, relative to the underlying trend, 12 years after the 2006 legislation was implemented and independently of TiRO. Collectively, these findings suggest that population-based policy and education interventions aimed at reducing second-hand smoke exposure could be durable and effective in reducing harm from second-hand smoke. Hospital admissions will capture only a small part of the impact of second-hand smoke exposure on childhood morbidity, and both the smoke-free public spaces legislation and TiRO are likely to have had a wider effect on child health and wellbeing. In particular, the interventions are likely to have reduced minor respiratory symptoms that do not require hospitalisation.

When looking at children across all ages and those younger than age 5 years, our analyses indicated an overall downward trend between 2000 and 2018 in asthma admissions, but found no significant deviation from that underlying trend following the introduction of either the smoke-free legislation in 2006 or TiRO in 2014. Furthermore, when our analysis split children into

	<5 years old	≥5 years old
Underlying trend	–0·15% (–0·42 to 0·12); p=0·28	0·53% (0·24 to 0·82); p<0·0001
Trend after smoke-free legislation (2006)	–0·36% (–0·67 to –0·05); p=0·021	–0·68% (–1·00 to –0·36); p<0·0001
Step-change after TiRO (2014)	8·27% (–4·36 to 22·57); p=0·21	14·06% (1·85 to 27·73); p=0·022
Trend after TiRO (2014)	–0·48% (–0·85 to –0·12); p=0·0096	–0·17% (–0·57 to 0·22); p=0·39

Data are mean (95% CI); p value. Underlying trend values show the mean percentage change in monthly admissions; trend values after the 2006 legislation and 2014 TiRO initiative show mean percentage change in monthly admissions relative to the underlying trend. Step-change values show the immediate change in the month the TiRO initiative was introduced. TiRO=Take it Right Outside.

Table 3: **Interrupted time-series analysis of asthma admissions in children stratified by age**

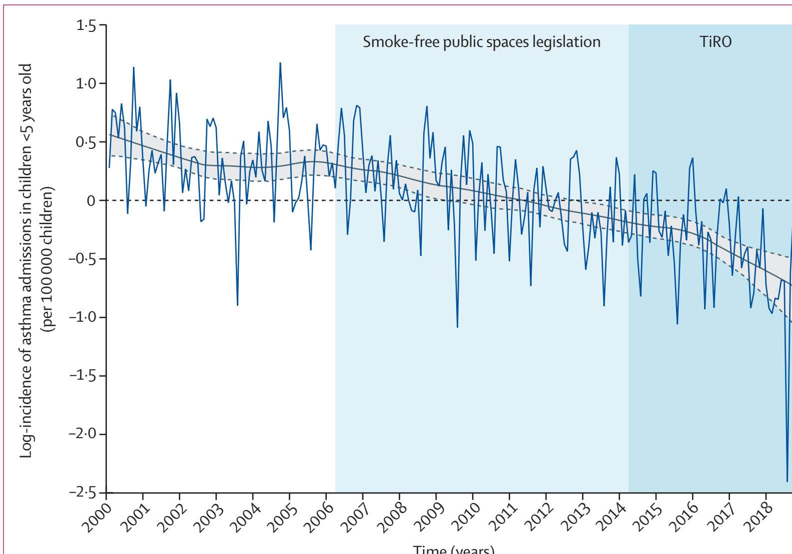

Figure 2: **Monthly hospital admissions for asthma per 100 000 children in Scotland for children younger than 5 years between Jan 1, 2000, and Dec 31, 2018**
The solid line indicates the mean log-transformed standardised number of admissions and the dotted lines indicate the bootstrapped 95% CIs. Vertical lines show the introduction of the smoke-free public spaces legislation in March, 2006, and the TiRO public health initiative in March, 2014. The appendix (p 2) shows the trend in asthma admissions in children aged 5–15 years. TiRO=Take it Right Outside.

	SIMD 1 (most deprived)	SIMD 3 (intermediate deprived)	SIMD 5 (least deprived)
Underlying trend	0·24% (–0·16 to 0·64); p=0·24	0·29% (–0·13 to 0·71); p=0·18	–0·18% (–0·56 to 0·20); p=0·35
Trend after smoke-free legislation (2006)	–0·49% (–0·87 to –0·11); p=0·011	–0·70% (–1·17 to –0·23); p=0·0043	–0·04% (–0·40 to 0·33); p=0·85
Step-change after TiRO (2014)	12·11% (–6·86 to 34·95); p=0·22	20·78% (–2·15 to 49·08); p=0·087	–10·95% (–21·81 to 1·42); p=0·079
Trend after TiRO (2014)	–0·34% (–0·88 to 0·20); p=0·21	–0·38% (–0·92 to 0·16); p=0·17	–0·14% (–0·53 to 0·24); p=0·46

Data are mean (95% CI); p value. Underlying trend values show the mean percentage change in monthly admissions; trend values after the 2006 legislation and 2014 TiRO initiative show mean percentage change in monthly admissions relative to the underlying trend. Step-change values show the immediate change in the month the TiRO initiative was introduced. TiRO=Take it Right Outside.

Table 4: **Interrupted time-series analysis of asthma admissions in children from the most deprived, intermediate deprived, and least deprived areas**

younger and older age groups, we identified an increasing underlying trend in asthma admissions amongst older children over the 2000–18 period. Overall, these observations suggest that while public health interventions to reduce second-hand smoke exposure might have been an important factor in reducing asthma admissions in some children, the absence of consistent trends across all age groups suggests that interventions at the individual patient level are also required to further reduce asthma admissions. Additional interventions might include routine use of objective tests for asthma control and optimising asthma preventer treatments and adherence to this treatment.

Although our study found an association between TiRO and reduced asthma admissions in young children, this does not prove causation. However, evidence suggests that the intervention could be directly linked to the observed decrease in asthma admissions. Firstly, an evaluation of TiRO[20] and other smoke-free home initiatives in the UK[8,9] showed that parents retain information concerning smoke-free homes, and in many cases implemented a change in their smoking behaviour. Secondly, the proportion of children with reported second-hand smoke exposure decreased after TiRO, from 12% in 2014 to 6% in 2015 and 2018.[6] There is no objective evidence of a decrease in child exposure to second-hand smoke after TiRO. However, a decrease in the concentration of salivary cotinine from tobacco, as an objective index of second-hand smoke exposure, was reported in children aged 11–12 years in Scotland after the 2006 legislation,[4] and non-smoking adults were around 6 times less likely to have had detectable second-hand smoke exposure in 2016 than in 1998.[21] The same might be assumed for children after TiRO. Thirdly, our analyses showed decreases in hospital admissions for asthma (and some other conditions related to second-hand smoke exposure) after the 2006 smoke-free public spaces legislation, and in some subgroups after TiRO in 2014, but admissions for gastroenteritis (a condition unrelated to second-hand smoke exposure) were unaffected. The associations reported fulfil many of the Bradford Hill criteria for causality,[22] including consistency, specificity, temporality, plausibility, and coherence, but should now be replicated in other settings.

We reasoned that the effect of TiRO would be most evident in young children, considering that cotinine concentrations in children whose parents smoke are higher in preschool children (age 1–5 years)[23] than in primary school children (age ~11 years).[4] The increased exposure to second-hand smoke in young children is probably a result of the higher proportion of time spent at home compared with older school-aged siblings.[24] Other possible reasons for the increased risk of harm from second-hand smoke exposure in young children include a faster respiratory rate and their tendency to play on the floor where they are close to second-hand smoke constituents.[25] Therefore, TiRO could have plausibly led to a decrease in the domestic exposure of young children to second-hand smoke, with a resultant effect on admissions for asthma. However, an unexpected finding was the positive step-change in asthma admissions among older children after TiRO. The TiRO intervention was not directed at young children and we believe that TiRO was unlikely to have simultaneously increased and decreased second-hand smoke exposure in households with both older and younger children.

The prevalence of smoking remains highest in the most deprived communities,[26] and TiRO might have been expected to have the greatest effect on asthma admissions among children from the most deprived areas of Scotland. We observed no difference in asthma admissions between SIMD deprivation categories after TiRO. By contrast, after the 2006 legislation, asthma admissions decreased in children from more deprived communities, but not in those from the least deprived communities. One possible reason for the legislation not being associated with decreasing asthma admissions in the least deprived group could be that smoking prevalence was already low in 2006. Therefore, a substantial reduction in second-hand smoke exposure was not possible and there was no associated reduction in asthma admissions.

Decreasing admissions for childhood asthma have been reported 3–6 years after the introduction of smoke-free legislation in Scotland,[12] England,[13] and the USA,[14] but we are not aware of any previous study that has reported a sustained effect after an interval of more than a decade. We acknowledge that other factors such as tobacco pricing and widespread use of electronic cigarettes might be important in the relationship between smoke-free legislation in 2006 and asthma admissions in 2018. Reducing second-hand smoke exposure in households in deprived communities is not easily achieved. One intervention, which sought to change the smoking behaviours of parents via motivational interviews and an objective measure of indoor air pollution, successfully reduced young children's domestic exposure to second-hand smoke[27] and was effective when targeted at households living in poverty in one study,[28] but not another study.[29] The 2006 smoke-free legislation focused on public spaces and was legally enforceable, whereas TiRO concerned domestic space and was not obligatory. These differences might explain the differing trends in asthma admissions between SIMD categories, particularly in terms of the decrease in asthma admissions in the lower two deprivation categories (SIMD 1 and 3) after 2006 but not after 2014. This might be explained by households in deprived communities changing smoking habits to meet legally enforceable requirements, while being unable to create a smoke-free home.

Our study had a number of limitations. As in any observational study, the finding of an association does not prove causation. Other public health interventions might at least partly explain the associations we reported. For example, the pneumococcal vaccination introduced across the UK in 2006 might explain the decrease in lower respiratory tract infection and acute otitis media admissions after the smoking legislation, although lower respiratory tract infection admissions actually increased in Scotland after introduction of the heptavalent pneumococcal vaccine in 2006.[30] No asthma-specific interventions were introduced in 2006 or 2014 that could account for the decrease in asthma admissions after these timepoints. Although our study sample was of sufficient size to undertake whole population analysis and subgroup analyses in young children and in children from deprived communities, numbers of admissions were insufficient for a meaningful analysis of children who were both younger than age 5 years and from the most deprived quintile. In the interests of disclosure protection, we were provided with aggregated data on admissions per month categorised by age and sex groups, and our analyses would have been improved if weekly admissions were available to assess for trends. A final limitation is that our analysis did not consider trends in smoking prevalence by deprivation; however, results from the Scottish Health Survey 2016 show prevalence to have decreased in a near-linear trend before and after the TiRO intervention,[31] and thus we assume it did not substantially affect the results.

In summary, we found that two initiatives aimed at reducing harm to children from second-hand smoke in Scotland were associated with decreases in hospital admissions among children for conditions related to second-hand smoke exposure, including a decrease in asthma admissions in young children. The first potential policy implication of our results is that smoke-free home interventions, which are known to alter parental smoking, might benefit the respiratory health of children. Our study also indicated an ongoing reduction in childhood conditions related to second-hand smoke exposure following the introduction of smoke-free legislation in 2006. Although causation cannot be inferred, these results further support policies that include legislation for smoke-free public spaces.

Contributors

ST conceived the study and collected the data. SD searched the literature. SD and ST wrote the first draft of the manuscript. DM analysed the data. SS and JPP provided public health perspectives. All authors were involved in data interpretation and made meaningful contributions to the final submitted manuscript.

Declaration of interests

We declare no competing interests.

Data sharing

Data are available on request to the corresponding author.

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