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Associations between PM_{10} from Traffic, Resuspension, Sand Storms and Volcanic Sources and Asthma Drugs Dispensing

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Research

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Abstract

Background

Particle matter (PM) is detrimental to respiratory health, particularly in individuals with underlying respiratory disease, e.g. asthma. In the capital area of Iceland PM is both from anthropogenic sources, mainly traffic and local resuspension, as well as natural sources, such as dust-and volcanic ash storms. The aim was to study the association between all kinds of PM events from and daily dispensing of asthma drug as a proxy for respiratory health.

Material and methods

The study period was 2005-2015. Dispensing of asthma drugs for all individuals living in the capital area of Iceland were obtained from health registries. Concentrations of daily air pollution, pollen, and meteorological variables were obtained. Dust sources were determined for days when PM exceeded the health limit (24-hour mean 50 $\mu g/m^3$) which are defined as “PM events”. The data were analysed using generalised non-linear models (GNM) methods and adjusted for both season and time trend.

Results

There were 137 PM event days where PM exceeded the health limit, and the source of the particles could be determined. The source of PM events was most often traffic (5%) or local resuspension 92(%), but PM events were also due to dust storms (1%) and volcanic ash (0.2%). During the 11 year study period there were on average 85 (standard deviation 45) daily dispensings of short-acting asthma drugs and 31 (19 standard deviations) dispensing of long-acting drugs.

In the regression analysis, PM events from traffic and resuspension sources were associated with increases in the number of individuals who filled prescriptions for both long- and short-acting asthma drug in the following 7 days. Volcanic ash PM events were associated with dispensing of long-acting drugs, and short-acting drug use in summer and in individuals aged less than 18 years.

Discussion

PM from traffic and local resuspension are the largest contributors to respiratory morbidity in Iceland’s capital area, although volcanic particles were also a significant contributor. PM from dust storms which did not originate from recent volcanic sources, was not associated with this indicator of poor respiratory health.

Introduction

Particle matter (PM) from natural sources are becoming increasingly important factors in the study of PM health effects as their effect on respiratory health has been shown in recent studies (1, 2). The studies of dust from the desert regions in North Africa, the Middle East and Asia report associations between natural all-cause and cardiorespiratory mortality and morbidity (3–5). Asian dust has been associated with increased ER visits for respiratory causes in children and adults (6–8). In the Middle East, dust storms have been associated with hospital admissions for COPD (9) and asthma drug dispensing in children (10). Recent studies have reported interactions between Asian dust and combustion particles to have a detrimental effect (11). It is possible that observed effects were due to PM levels being higher during non-anthropogenic PM events than during anthropological events (12), but experimental studies suggest that the detrimental effects of PM from natural sources are due to biological material carried with desert dust particles (1).

Iceland is a large regional source of natural dust pollution for the north Atlantic (13–16). Icelandic dust storms are among the fiercest on the planet (15). Following the eruption of Eyjafjallajökull 2010 and Grímsvötn 2011, volcanic ash has been added to the natural dust mix (17, 18). Surface particles in Iceland contain volcanic material with 5-50 % glassy particles, with the highest percentage found in fresh volcanic ash (Butwin et al., 2019). Additionally, air pollution levels due to traffic in the Icelandic capital region match those of continental Europe (19) with resuspended dust made up of mechanical wear particles (studded tyres contribute to this (20)), salt, and previously emitted combustion particles and other dust particles (21). Recent studies have pointed out the importance of both natural dust and anthropogenic particles as mediators of health effects (22).

With this new recognition of the importance of natural dust, it is pertinent to investigate effects of subarctic natural dust on human health using asthma drug as a proxy for respiratory morbidity (23). Previous studies in the current study setting (24) have been partly inconclusive.

The aim of this study was to utilize the comprehensive Icelandic health registers of health outcomes, a longer study period, as well as a thorough source-appointment to investigate the association between natural dust air pollution, volcanic ash and anthropogenic particles and dispensing of asthma drug.

Material And Methods

The study period was from 1 January 2005 to 31 December 2015. Altogether 4017 days. The study region was the Icelandic Capital area with Reykjavik and its surrounding municipalities (population 210.000 in 2015).

Health data

Data on all pharmacy-dispensed asthma drugs was obtained from the Icelandic Directorate of health databases. (https://www.landlaeknir.is/tolfraedi-og-rannsoknir/rannsoknir/) The asthma drug dispensing data were obtained along with age, sex, drug type, and postcode for the study period. The data were aggregated by date into time series of total daily number of individuals getting dispensed short-acting, or long-asthma drugs (ATC codes R03A and R03B) (25), stratified by age categories younger (<18 years of age), adult (18-64 years of age) and older (>64 years of age) as well as males and females.

Air pollution data

The Iceland Environmental Agency and the Reykjavik municipality continually measures air pollution and climate at an urban roadside station in Reykjavík: PM_{10}, NO_2, H_2S, SO_2, O_3 and H_2S (H_2S only been measured since 2006)(26). These data were converted into 24-hour (daily) means from midnight to midnight. PM events (days exceeding the health limit) in Reykjavik due to ash storms occurred following the Eyjafjallajökull eruption in 2010 (17) and were easily identified by the source areas and magnitude. Dust storms from known source regions (14), of which the deposited ash becomes part of (26) are identified by wind direction and speed. The definition is rather strict, so only events that can definitely be traced to dust source areas are included. PM events due to traffic are identified by traffic volume, of which NO_x is a good proxy. Finally, there are local resuspension events, when the winds exceed about 5 m/s and PM levels rise. Additionally, fireworks events on New Year's Day have a very clear signature (27) and remote pollution events occur infrequently, but these were rare. Dust and ash particles smaller than 10 µm are both crystalline and blocky in nature and are expected to have similar health effects; as long-as there is no chemical coating on the ash particles (28). The exposures of interest were days with PM events with contributions from either natural dust, volcanic ash, traffic particles and dust from local resuspension; categorized for days over the health limit.

Covariates

Daily means of NO_2, SO_2, were introduced to the models as covariates. Pollen data was obtained from the Icelandic Institute of Natural History (www.ni.is) as daily values of grass, birch and total pollen per m^3 air. Individuals with influenza symptoms are reported to Chief Epidemiologist at the Directorate of Health (https://www.landlaeknir.is/smit-og-sottvarnir/smitsjukdomar/tilkynningarskyldir-sjukdomar/) and we considered 300 cases per week (approximately 1 case per 1000 inhabitants nationwide) indicative of an epidemic and coded as an indicator variable. Daily temperature measurements were obtained from the Icelandic meteorological office (www.vedur.is) and the Icelandic Environmental Agency (https://api.ust.is/aq)

Statistical methods

Using generalized non-linear regression models, GNM, with distributed lags allowing for differentiated lag and value effects using distributed lag non-linear model (DLNM) (29) we initially examined the association between air pollution and sources and asthma drug dispensing for lags up to 15 days as suggested by (23), but upon inspecting the results, settled on 7 days lag.

For the pollutants, temperature, and pollen, lag-concentration matrix (a *crossbasis*) (30) were defined with natural splines for the variable values, and a polynomic spline with three degrees of freedom for lags up to 7 days. For the source values, different degrees of freedom were tested, but penalized splines with 6 degrees of freedom were the best fit for the models of short-acting drugs. For long-acting drugs, penalized splines with 7 degrees of freedom was the best fit in ANOVA tests comparing the models. All models were adjusted for flu season, odd holidays, pollen, and temperature. The models were additionally adjusted for overall time trend, annual time trend, and weekdays.

Firstly, we regressed the dispensing of short-acting asthma drugs and air pollution and individual dust sources, traffic, resuspension, volcanic ash and sand storms, in separate, single exposure (unadjusted) models. Secondly, each pollutant source model was adjusted for co-pollutants NO_2 and SO_2 (adjusted models). Finally, the models were also adjusted for PM_{10} concentrations. As there was a lot of missing data in the time series of H_2S and O_3, there were not sufficient data to report results for all sources in analyses adjusted for H_2S and O_3 as main results (some are reported in the supplement). In sensitivity analysis, dispensing of long-acting drugs, and dispensing of short-acting drugs by age category, sex, and season were analysed with adjusted models. Summer season was defined as April to September, and Winter October to March. The associated effects were predicted from those models for relevant lags.

All analyses were performed with R (31). The results are reported as relative risk (RR) from the unadjusted (uRR) and adjusted (aRR) models, with their 95% confidence interval (CI) per interquartile range (IQR) for the pollutants, and per unit, for the PM events.

Results

Descriptive results

In the time series, there were 4016 days, of which 107 had a PM event with some contribution from traffic, 92 with contribution from local resuspension, 9 with contribution from volcanic eruptions, and 37 with contribution from natural sand storms, some events were mixed and had several sources (see Table S2). Time series of all pollutants in the study are found in Figure S1.

In the descriptive statistics for PM_{10} and gaseous air pollutants, we observe a small seasonal trend where the levels of most pollutants tend to be higher in the cold half of the year. This trend was strongest for NO_2, which had a mean value of 15.5 μg/m^3 in summer and 23.7 μg/m^3 in winter and weakest for SO_2 with a summer season mean of 1.4 μg/m^3 versus 1.3 μg/m^3 in winter (Table 1).

In the time series, there were on average 85 individuals per day who were dispensed short-acting drugs (R03A) and 31 were dispensed long-acting drugs (R03B). For both medicine subtypes, there is a weak tendency for the number of dispensing to be higher in winter, e.g. 90 vs 80 for short-acting drugs (Table 2).

During the study period, the daily number of individuals using asthma drugs increased, thus, the average number of individuals using short-acting and long-acting drugs per day were 76 and 23 in 2005, respectively, and in 2015, it was 102 and 38 respectively (a 68% and 34% increase, respectively, Figure 1). In context, the study population increased 15% from 2005 to 1 January 2015. The extremely high values in spring 2013 are associated with a change in the health care reimbursement scheme.

Regression results

PM events caused by traffic were associated with increased dispensing of short-acting asthma drugs. SO_2 and PM_{10} concentrations were positively associated with asthma drugs dispensing in all relevant models, whereas the association between asthma drugs and NO_2 was not significant in models who were not adjusted for exposure to other pollutants (Table 3). Analysing long-acting drugs, there was a large increase in the number of dispensing associated with PM events from traffic (uRR 1.44 and aRR1.48 in univariate models and adjusted models, respectively) and volcanic ash (uRR 2.91 and aRR 3.13, respectively) (Table 4). For the pollutants, there were positive associations between SO_2 and PM_{10} and dispensing of short-acting asthma drugs in univariate models, and SO_2 and NO_2 in the two-pollutant models that were adjusted for PM events (Table 3). Similar associations were observed for long-acting drugs, but in the two-pollutant model, the association with NO_2 did not reach statistical significance (Table 4).

When inspecting lag structures of the associations between drug dispensing and PM events, the effects of traffic PM events occurred at lag 2-6 days (Figure 2a), local resuspension PM events were associated with increases at lag 0. For volcanic PM events, the maximum increases occurred at lag 2 and lag 3, and for sand storm PM events, the highest risks occurred at lags 5 and 6 (Figure 2c-d).

In subsets stratified by sex, there no differences in risk for either source or drug type (Figure 3ab). Stratifying by age group, we found that PM events due to traffic were associated with increased dispensing of short-acting drugs in the young and adult people. PM events due to resuspension was associated with increased risk in elderly (Figure 3a). Volcanic PM events were associated with increased risk in adults. Stratifying the data by season, PM events due to traffic were only significantly associated with short-acting asthma drugs dispensing in winter, whereas resuspension was only associated with asthma drugs dispensing in summer. PM events due to volcanic sources and dust storms were positively associated with short-acting asthma drug dispensing in summer, but negatively in winter, where there were very few such events (1 and 8 respectively). There were no significant associations observed with dust storms (Figure 3a).

For the long-acting drugs (Figure 3b), the stratification of age groups revealed the PM events from traffic sources was associated with the highest risk in young people by RR 1.95, events from volcanic events was associated with statistically significant increases in young people and adults, with the highest RR in adults at 6.54. PM events from traffic was only associated with increases in young people. There was a significant association between resuspension PM events and increased long-acting asthma drugs dispensing in elderly. Again, there were small non-significant differences between females and males, except that resuspension events were associated with increased risk in females, but not males. Stratifying by season, volcanic events were only associated with increased dispensing in summer, and PM events from traffic sources were only associated with increases in long-acting asthma drugs in winter (Figure 3b).

Discussion

In this study of the association between PM events and dispensing of short- and long-acting asthma drugs, we found that PM events from traffic were associated with increased dispensing of short-acting asthma drugs (Table 3). Dispensing of long-acting asthma drugs, which accounts for one fourth of total asthma drug dispensing and most of the seasonal variation (Table 2) had a higher RR of association for PM events from volcanic sources in the adjusted models than dispensing of the short-acting drugs (RR 1.17 vs 3.13) (Table 3 and Table 4). This association was present in both single- and multi-source models with and without adjusting for other pollutants (correlation matrix for the pollutants in presented in the supplement Table S2).

We found that PM from volcanic eruptions were associated with increased asthma drug dispensing in adults in summer, and furthermore, the dispensing of long-acting drugs were increased following volcanic ash events, suggesting that the individuals affected by this type of pollution tend to be individuals with chronic disease. All volcanic ash events occurred during 2010, and save for one, within six months of the Eyjafjallajökull eruption 2010. Only one volcanic ash event occurred during winter, and thus, the results for that period suffers from very low statistical power (Figure 3 ab).

Perhaps users of long-acting drug are more sensitive to volcanic ash events, or, they are more likely to comply with official advice or increased awareness during the rather short period following the eruption. The results for winter, where there were also very few natural dust and volcanic events, differed somewhat from summer results. However, these differences could also be due to climate factors. Inspecting the effects of temperature from the adjusted model, it is somewhat different in warm and cold temperatures and is associated with reduction in dispensing following low temperatures, and increases after high temperatures (Figure S2).

Although Icelandic dust storm particles, smaller than 10 µm, have properties similar to volcanic ash (28), we found a negative association between dust storms and asthma drug dispensing. All surface particles in Iceland, which are inherently volcanic in origin, contain glassy particles, whereas freshly erupted volcanic particles contain up to 50% glassy particles, but only in particles larger than approximately 20µm is the morphology of Icelandic dust truly volcanic in nature (Butwin et al., 2020) and those particles will be beyond the respirable size fraction. Dust storms typically occur during dry and windy conditions, meaning that simultaneous build-up of gaseous traffic related air pollution and pollen within the study area is unlikely. This could possibly bias the estimated effects of dust towards a lower estimate. However, adjusting for other pollutants, weather and pollen in our models should have accounted for this, although some residual effects may remain. Most dust storms also occur during summer, where there are fewer infectious disease epidemics and asthma drug use is generally lower (Table 1). We can also speculate, that the effects of sand storms on dispensing are transient, as we see in Figure 2 that sand storm has positive (albeit not significant) associations with dispensing at lag 0. This observation is concurrent with the results of Novack and colleagues (12) who found associations between asthma drug dispensing and dust storms at lag 0-2. In our study, PM events from natural dust have lower PM_{10} concentration than during the volcanic PM events, and it is possible that the PM levels in the capital area are not sufficiently high to induce the adverse mechanical respiratory health effects which are postulated in previous studies (12).

Traffic and local resuspension

Resuspended particles from roads, with contribution from mechanically worn road surface, particles from tires and brake wear, and salt, are generally coarser than particles which are directly associated with exhaust from traffic (19, 20, 32). $PM_{2.5}$ was available for only some parts of the study period, so we refrained from adjusting for this in our models. Finding mainly effects of PM_{10} from traffic has been reported in other studies of specific PM sources, where long-term exposure to particles from marine traffic or residential heating were not associated with respiratory health (33). However, when studying health effects of long-term exposure to air pollution, it is not unproblematic to disentangle resuspension and direct traffic exposure in dispersion models as these are highly correlated, giving extra importance to short-term studies with thorough source assignment.

In relation to literature

Dispensing of asthma drug is an indicator of respiratory health in a population (23). Only few studies of asthma drug in association with natural dust exist; (10) reported that in a cohort of children with asthma, drug purchases were increased after desert dust storms, peaking at lag of 3 days. In pre-school age children, asthma emergency department visits nearly doubled (OR 1.8, 95% CI 1.2-2.8) after Asian dust events in Nagasaki, Japan (7). Emergency room visits for respiratory causes increased by 14% after dust events, most for elderly and adult men in Lanzhou, China (8). Admissions for COPD increased during dust storm days in vicinity of Middle Eastern Negev desert (9). Recently, more specific studies have found that the effects on lung function was specific to the source of the particles, so Asian dust in concert with combustion particles had a detrimental effect (11) and furthermore, there are speculations that the detrimental effects of PM from natural sources are due to biological material carried with desert dust particles (1).

For other respiratory outcomes, a number of studies have found increases in association with PM from natural sources or dust storms. In East Asia, dust episodes are associated with respiratory health outcomes, but researchers have speculated that Asian dust modified the effect of $PM_{2.5}$ to make it less harmful to health (34). Also, researchers from Asia indicate that PM events should be considered as outliers in analyses of PM health effects (35); (34). In our analyses, dust storms were also associated with decreased RR, which could be reflective of a similar phenomenon. In a Southern European meta-analysis it was estimated that mortality increased by 0.51 % per 10 ^{3} desert PM_{10} and observed similar estimates for cardiorespiratory causes (5) and mortality (2).

Modelling issues

Effect estimates for volcanic ash were positive in either model, but did not reach statistical significance, probably due to the low number of events. Estimated risks were higher in the adjusted models for some sources, indicating that accounting for the contribution from other pollutants strengthened the results. However, the confidence intervals overlapped. In the graphical representation of the lag-association (Fig. 2), the CI bands indicate that the statistical power for traffic and resuspension was superior, as these events were the most common.

In a sensitivity analysis excluding the year 2010, the effect estimates for PM events from traffic remained statistically significant, but other estimates were not significant (data not shown).

NO_2 was mainly associated with traffic pollution, and in all models, there was a positive association between NO_2 and dispensing. For SO_2, there was a special case in fall-winter 2014 when there was substantial SO_2 contribution from the volcanic eruption in Holuhraun (36), but none of the PM events occurred during days where the volcanic plume was over the capital area. However, we performed sensitivity analysis of the data without the days with volcanic plume as well as excluding the whole eruption period, and the results were only marginally altered (data not shown). Thus, we are confident in the robustness of our results.

In the main analysis (Table 3 and Table 4), we did not adjust for PM_{10} to avoid bias, as our exposure metric, the pre-defined PM events, are inherently strongly associated with PM_{10}, however, we report results adjusted for PM_{10} in the supplement (Table S3). In these models, the estimates of PM_{10} then corresponds to the effect of PM_{10} under 50 μg/m^3.

There was a lot of missing data in the time series for O_3 and H_2S, also during PM event days, so full results cannot be reported with adjustment for these pollutants. After adjusting for O_3 and H_2S, the associations with traffic PM events did not reach statistical significance and there were no volcanic PM events left in the time series, so results cannot be reported for those (Supplementary Table S4).

In the analysis, we used the generalized non-linear model which were adjusted for time trends using standard methods to estimate the effects of PM events, but it can be argued that a case-crossover design could be more reasonable as adjustment for season and time trend are inherent in the model specifications. However, tests of these models revealed that they performed poorly, perhaps as the PM events were both rather rare, and, in the case of volcanic events, occurred within the span of a few months.

Limitations and strengths

As with all pharmaco-epidemiological studies, there is some uncertainty associated with the causal chain from the onset of the biological effect (asthma exacerbation due to PM exposure) and the measured outcome (individuals filling prescription in a pharmacy). This chain is modified by availability (perhaps the individual has recently filled his prescription the week prior to the event, perhaps the event occurs during the weekend where pharmacies have limited opening hours. These factors mean that the uncertainty of the observed association must be treated with some caution, even more so than in a study with a direct clinically measured outcome.

A strength of this study is the long time series of data and the presence of many environmental covariates. Despite the extent of the study period, there were only 9 days with contribution from volcanic eruptions, all from the Eyjafjallajökull eruption. The data has been collected prospectively and subjects would in must studies be unaware of their exposure status. It is a limitation that there is no information about individual-level covariates of interest such as smoking status and co-morbidities, as these might be of interest for subset analysis, to further investigate groups with respiratory susceptibilities.

During the exposure period, there was also the Holuhraun volcanic eruption 2014-2015, but the days with high exposure (either SO_2 over the health limit, or mature volcanic plume (37) from that eruption did not coincide with any of the specific source PM events in the current study. The capital area is scarcely the most affected area, but studies of more affected areas are hampered by a severe lack of measurements (data not shown).

Conclusion

In this long time series study, all asthma drug dispensing was increased following PM events from traffic and resuspension, but volcanic contributions were only associated with increases in adults and long-acting drugs. A study on an outcome with less risk of bias from official advice is needed to establish if the observed results for volcanic PM events reflect actual increases in respiratory symptoms in the population.

Declarations

Consent for publication – does not apply

Availability of data and material – the data that support the findings of this study are available from The Icelandic Directorate of Health but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Icelandic Directorate of Health and the Icelandic Science Bioethics Committee.

Competing interests – the authors declare no competing interests.

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Ethics approval and consent to participate - The health data usage was approved by the Icelandic Directorate of Health and the Science Bioethics Committee (Ref : VSNb2016-080007/03.03)

Authors' contributions - HKC procured the background exposure data and outcomes data, analysed the data, wrote the first draft and made the illustrations. TT provided the volcanic source data, aided with the analysis, discussion and reviewing of the manuscript.

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Tables

Table 1 Descriptive statistics of the background exposure variables and frequency of particle matter (PM) events 2005-2015 by season

		All year				Winter				Summer			
	Missing	**Mean (SD)**	**25th centile**	**Median**	**75th centile**	**Mean**	**25th centile**	**Median**	**75th centile**	**Mean**	**25th centile**	**Median**	**75th centile**
PM_{10} (µg/m^3)	-	22.7 (18.0)	13.2	17.6	24.8	24.4 (19.8)	13.6	18.5	27.2	20.8 (15.3)	12.7	16.5	22.8
NO_2 (µg/m^3)	-	19.8 (11.6)	11.6	17.3	24.9	23.7 (12.7)	15.1	20.8	30.6	15.5 (9.0)	9.8	13.7	18.3
SO_2 (µg/m^3)	20	1.4 (1.0)	0.6	1.2	2.1	1.3 (1.0)	0.6	1.1	1.9	1.4 (1.0)	0.6	1.2	1.9
H_2S (µg/m^3)	621	3.3 (5.4)	0.8	1.7	3.7	4.6 (7.0)	1.3	2.4	5.4	1.8 (1.9)	1.3	2.4	5.46
O_3 (µg/m^3)	1837	37.6 (13.0)	28.4	36.6	46.7	38.4 (16.8)	30.9	38.0	47.3	36.6 (13.8)	27.0	35.9	45.6
		Days (%)				**Days**				**Days (%)**			
All PM events		187 (5)				119				68			
Traffic source		107 (3)				87				20			
Local resuspension		92 (2)				62				30			
Volcanic ash		9 (0)				1				8			
Dust storms		37 (1)				8				29			
Pollen (grains/m^3)		1624 (40)				0				1624 (81)			
Influenza, n (%)		611 (15)				490 (25)				121 (6)			

SD: Standard deviation. Summer is defined as months of April to September, winter October to March. Influenza denotes days with influenza epidemic.

Table 2 Descriptive statistics of daily asthma drugs dispensing 2005-2015.

	All year				Summer				Winter			
	Mean (SD)	25th centile	Median	75 th centile	Mean (SD)	25 th centile	Median	75 th centile	Mean (SD)	25 th	Median	75 th centile
Short-acting drugs												
Total	85 (45)	37	97	116	80 (45)	32	92	110	90 (44)	42	103	121
Age under 18	17 (10)	9	16	23	13 (8)	7	12	18	20 (10)	12	20	27
Age 18-64 years	44 (23)	20	49	59	43 (24)	18	49	59	44 (22)	22	49	60
Age 65 and older	25 (16)	9	27	36	24 (17)	7	27	35	25 (15)	10	28	36
Long-acting mediction												
Total	31 (19)	14	28	46	28 (19)	12	25	42	34 (19)	17	32	49
Age under 18	9 (6)	5	8	13	7 (5)	5	3	6	12 (7)	7	11	16
Age 18-64 years	11 (8)	4	9	17	11 (8)	8	4	8	11 (8)	5	9	17
Age 65 and older	10 (8)	3	10	16	10 (8)	8	3	9	11 (8)	4	10	16
SD: Standard deviation. Summer is defined as months of April to September, winter October to March. Short-acting drugs: ATC code R03A, Long acting drugs: ATC code R03B.												

Table 3 Air pollution and PM events from different sources and associations with short-acting asthma drugs dispensing and at lag days 0 to 7

	Models adjusted for a single source- or pollutant		**Models adjusted for PM event + NO_2 + SO_2**	
	uRR	95% CI	aRR	95% CI
Traffic	**1.24**	**1.06–1.46**	**1.27**	**1.08–1.50**
Resuspension	0.92	0.78–1.08	0.96	0.81–1.14
Volcanic	1.11	0.76–1.61	1.16	0.80–1.69
Dust storm	1.00	0.77–1.32	1.03	0.79–1.36
NO_2	0.99	0.98–1.00	1.00	1.00–1.00
SO_2	**1.00**	**1.00–1.00**	**1.00**	**1.00–1.00**
PM_{10}	**1.01**	**1.00–1.02**	-	-
Unadjusted models (uRR) only contained one exposure of interest, adjusted models (aRR) contained a PM source, NO_2 and SO_2. All models are adjusted for pollen, influenza season, temperature, and flu season, odd holidays, day of week, season and time trend. aRR associated with air pollutants NO_2 and SO_2 presented per IQR (NO2: 13.0 μg/m^3, SO2 1.4 μg/m^3, PM_{10}; 12.0, μg/m^3). The estimated aRR for pollutants NO_2, SO_2 and PM_{10} are from models adjusted for traffic PM events.				

Table 4 Air pollution and PM events from different sources and associations with long-acting asthma drugs dispensing at lag days 0 to 7

	Models adjusted for a single source- or pollutant		Models adjusted for PM event + NO_2 + SO_2	
	uRR	95% CI	aRR	95% CI
Traffic	**1.44**	**1.16–1.78**	**1.47**	**1.17–1.83**
Resuspension	1.13	0.91–1.40	1.19	0.95–1.49
Volcanic	**2.91**	**1.89–4.47**	**3.07**	**1.99–4.74**
Dust storm	0.51	0.35–0.78	0.51	0.34–0.75
NO_2	**0.98**	**0.96–0.99**	1.00	1.00–1.00
SO_2	1.00	1.00–1.00	1.00	1.00–1.00
PM_{10}	**1.02**	**1.01–1.04**	-	-

Unadjusted models (uRR) only contained one exposure of interest, adjusted models (aRR) contained a PM source, NO_2 and SO_2. All models are adjusted for pollen, influenza season, temperature, and flu season, odd holidays, day of week, season and time trend. aRR associated with air pollutants NO_2 and SO_2 presented per IQR (NO2: 13.0 μg/m^3, SO2 1.4 μg/m^3, PM_{10}; 12.0, μg/m^3). The estimated aRR for pollutants NO_2, SO_2 and PM_{10} are from models adjusted for traffic PM events.

Figures

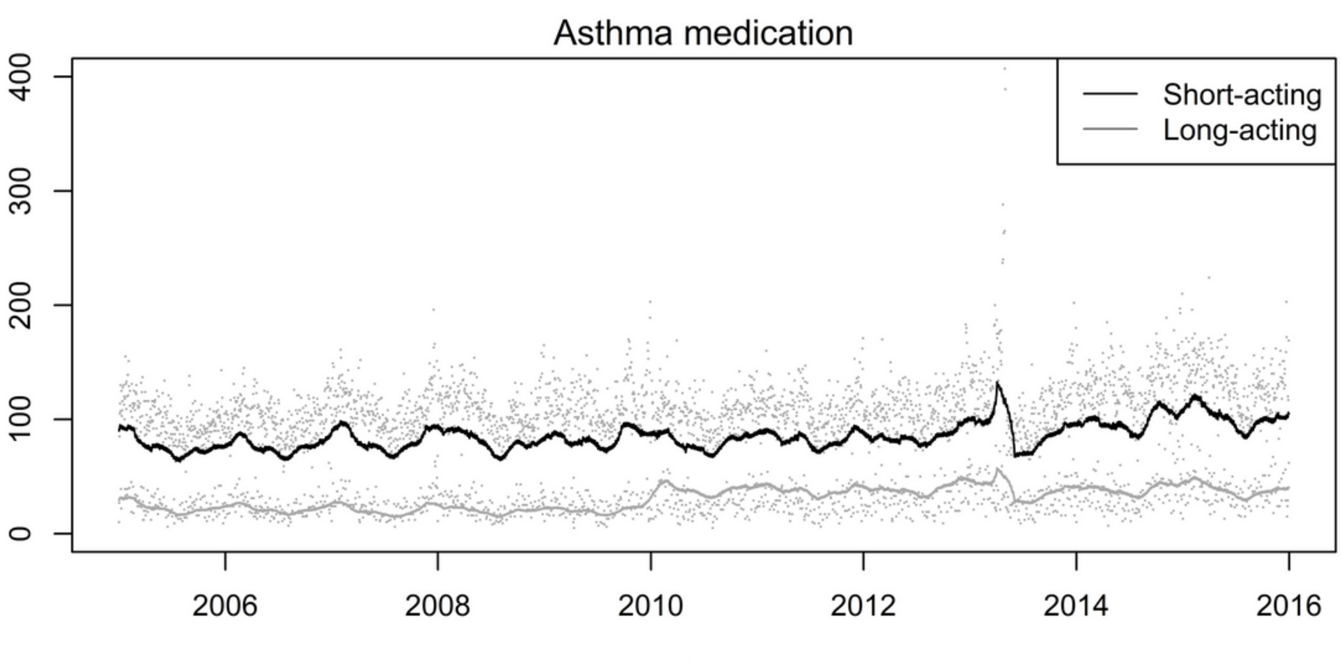

Figure 1

Time series plot of daily asthma drugs dispensing (number of individuals per day) 2005-2015

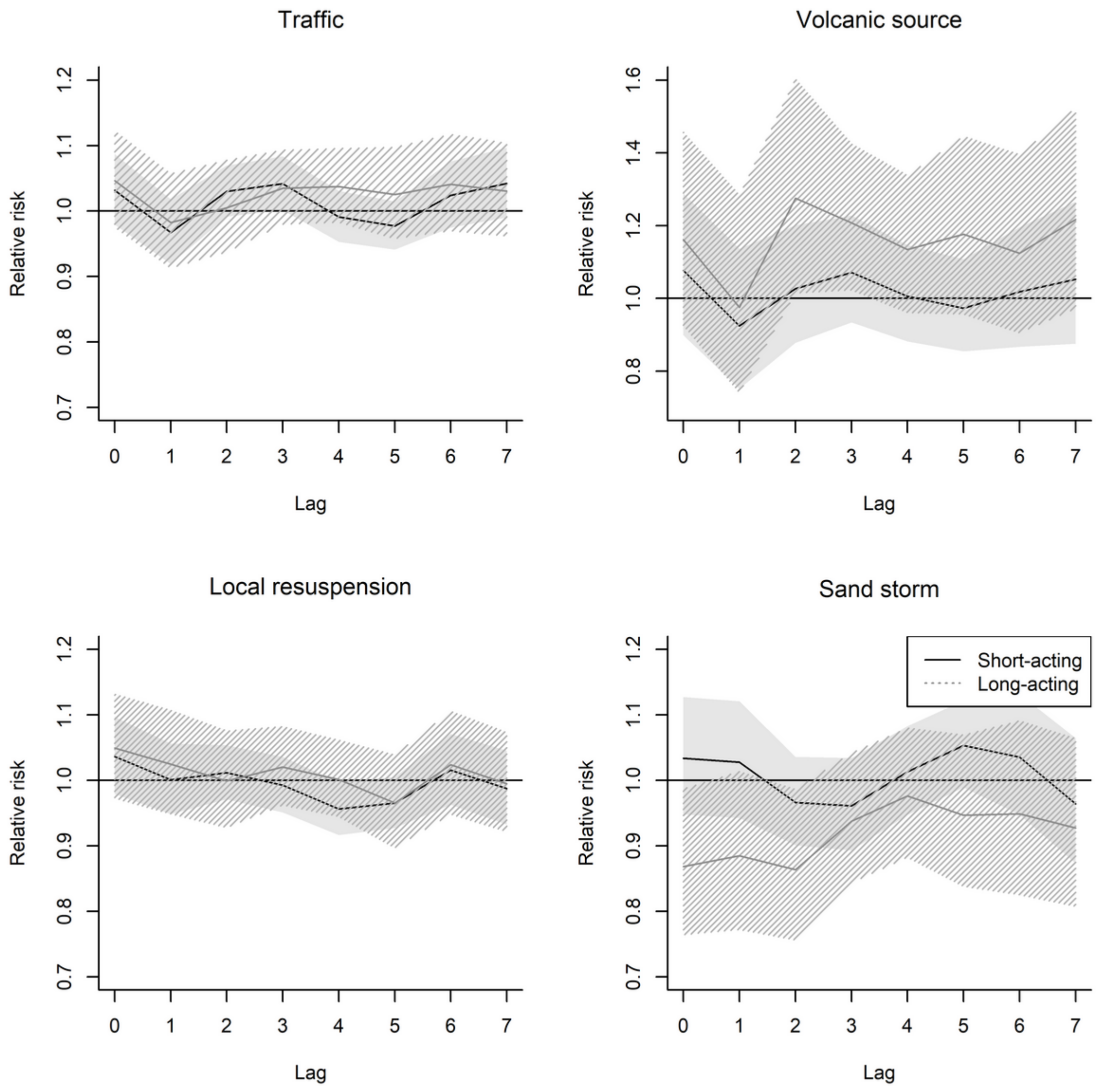

Figure 2

Lag-associations between PM sources and short-, and long-acting asthma medication dispensing at lag 0-7, plotted from models adjusted for SO2 and NO2, pollen, temperature, odd holidays, day of week, time trend and seasonal trends.

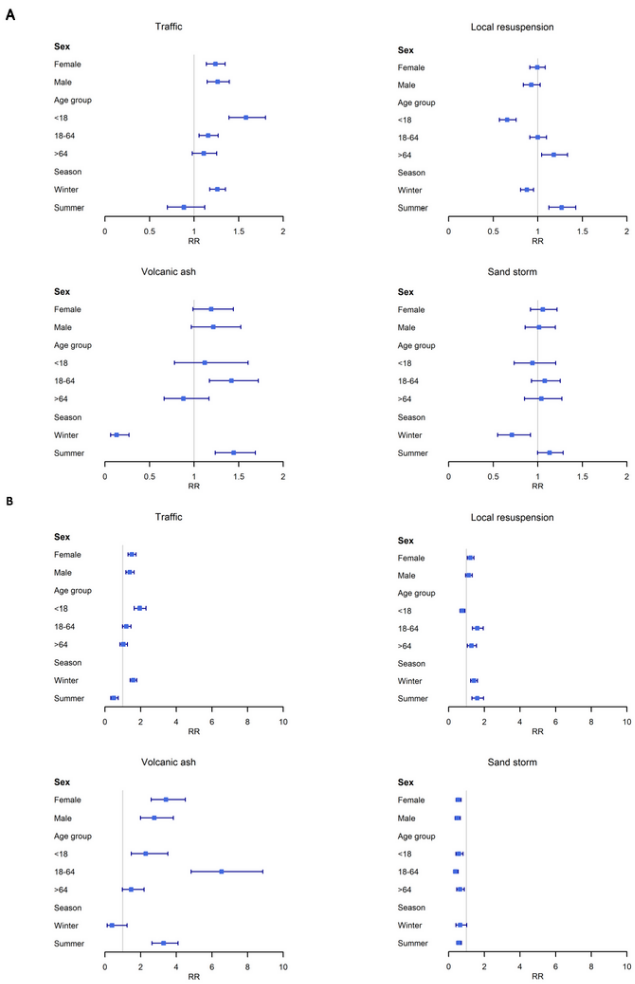

Figure 3

PM sources and their association with dispensing of short-acting asthma drugs (A) and long-acting drugs (B) stratified by age categories, sex, and seasons in models adjusted for SO2 and NO2pollutants, pollen, temperature, odd holidays, day of week, time trend and seasonal trends. at lag 0-7. Summer season defined as April to September. Source effects are modelled with natural splines for the values and third–degree polynomials.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarymaterial211008.docx