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Short term effects of air pollution on emergency hospital admissions for respiratory disease: results of the APHEA project in two major cities in The Netherlands, 1977–89

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Abstract

Study objective **– To assess the short term relationship between air pollution and the daily number of emergency hospital admissions for respiratory disease.**

Design **– Data were analysed using autoregressive Poisson regression allowing for overdispersion and controlling for possible confounding factors such as seasonal and other chronological variables, meteorological factors, and influenza epidemics.**

Setting **– The two major cities in The Netherlands – Amsterdam (694 700 inhabitants) and Rotterdam (576 200 inhabitants).**

Participants and measurements **– Emergency hospital admissions for respiratory diseases, registered on a daily basis by the National Medical Registration, for the period 1977–89 were used. ICD-9 codes included were: respiratory (460–519), chronic obstructive pulmonary disease (490–492, 494, 496), and asthma (493). The mean (range) of the total daily number of admissions for these three classifications were as follows: 6·70 (0–23), 1·74 (0–9) and 1·13 (0–7) respectively in Amsterdam and 4·79 (0–19), 1·57 (0–9), and 0·53 (0–5) in Rotterdam. Air pollution measurements were provided by the National Institute of Public Health and Environmental Protection. In The Netherlands, air pollution is at a low to moderate ("summer type") or a low ("winter type") level. The levels in Amsterdam and Rotterdam did not differ much for the "summer type". For 1977–89 the mean (range) values of ozone (O_3), the "summer type" pollutant (O_3–8 h), were 86 (0–252) µg/m^3 in Amsterdam and 82 (0–286) µg/m^3 in Rotterdam. The mean (range) of the values "winter type", pollutant, sulphur dioxide (SO_2–24 h), were 38 (0–381) µg/m^3 in Amsterdam and 50 (1–379) µg/m^3 in Rotterdam. For black smoke (BS–24 h), values were 14 (1–84) µg/m^3 and 28 (1–144) µg/m^3 respectively (1986–89).**

Main results **– Ozone had a non-significant positive effect on the number of respiratory emergency admissions in summer in people aged ≥65 years (relative risk for a 100 µg/m^3 increase in O_3–8 h of 1·127 (0·983, 1·292) in Amsterdam and a significant positive effect of 1·344 (1·097, 1·647) in 1977–81 in Rotterdam). Sulphur dioxide did not show any clear effects; in Amsterdam a significant negative effect was even found. The same was true for nitrogen dioxide in Amsterdam; in Rotterdam, however, nitrogen dioxide showed non-significant positive effects (RR 0·965, 1·342). Black smoke did not show any clear effects in Amsterdam; in Rotterdam it was positively but not significantly related to the number of admissions.**

Conclusions **– The results show that the relation between short term air pollution and emergency hospital admissions is not always consistent at these rather low levels of daily hospital admissions and of air pollution.**

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It is well known that high levels of air pollution have important short term effects on human health.[1-2] More recent evidence[3-17] indicates that short term health effects are measurable at lower levels of air pollution, even below the limits set by international organisations.[18] These reports consistently show that small but statistically significant increases in mortality and hospital emergency visits and admissions are associated with small short term increases in air pollution. The APHEA project[19] tries to assess adequately these short term health effects of moderate and lower air pollution levels in Europe in a standardised way. The Dutch participation in the APHEA project is presented here.

In The Netherlands, only a few studies that examine the effect of air pollution on health have been undertaken. In 1969 and 1972, van der Lende *et al*[20] measured the IVC and FEV_1 of both an urban and a rural adult population. In 1969, a peak in air pollution in the urban area caused a decrease in pulmonary function. Other investigations of the effects of air pollution on respiratory health of Dutch children showed associations between air pollution levels and pulmonary function, bronchodilator use, and peak flow.[13 15-17] Recently, Hoek *et al.*[21] examined mortality and morbidity in Rotterdam in the winters of the early 1960s. Borderline associations between black smoke (BS) and sulphur dioxide (SO_2) concentrations and both mortality and the number of hospital admissions were found. In the early 1960s, air pollution levels were rather high: the average

SO_2 concentration was 219 μg/m^3 (range 46–1159 μg/m^3 and the average BS concentration was 168 μg/m^3 (range 25–529 μg/m^3). Air pollution levels have fallen steadily since then.

This paper concerns the short term effects of "summer type" and "winter type" pollutants on hospital emergency admissions during the period of 1 April 1977 to 30 September 1989 in the two major cities in The Netherlands, Amsterdam and Rotterdam.

Methods

STUDY POPULATION

The data used in this study are part of the data collected for a project (financially supported by the Ministry of Housing, Planning and Environment) which analysed the relation between episodes of air pollution and hospital admission for the whole of The Netherlands between 1977 and 1989. During the APHEA project it was decided to concentrate on the relation between air pollution and health in urban areas. Amsterdam (694 700 inhabitants in 1989) and Rotterdam (576 200 inhabitants) are the two major cities in The Netherlands; they are surrounded by highways and have moderate to low air pollution in summer as well as in winter.

AIR POLLUTION MEASUREMENTS

Air pollution data were provided by the National Institute of Public Health and Environmental Protection and consist of measurements of the national network of air quality.

The pollution parameters used were daily means for SO_2, nitrogen dioxide (NO_2) and BS, one hour maximum values for SO_2, NO_2 and ozone (O_3) and eight hour maximum values for O_3. SO_2 was measured by gas-phase fluorescence, NO_2 and O_3 by chemiluminescence, and BS by the OECD method. Data for 1977–89 were available for all pollutants except for BS (values for 1986–89). Since Amsterdam and Rotterdam are small cities only one station is situated in each. These city stations are located in streets with fewer than 2750 motor vehicles passing in 24 hours in a circle of 35 metres around the stations. They are located in the built up area of the town and are representative of the city background concentrations. Data from these city stations were used as much as possible, except for O_3, for which a station at a suburban site was selected. The reason for this is that suburban sites are more representative of fluctuations in O_3 exposure than central sites where O_3 concentrations tend to be lower as a result of higher NO_2 levels.

To deal with the problem of missing data, stations within 25 km of the city station were selected and used as predictors of the values of the city station by means of linear regression (as mentioned in the APHEA protocol). In Amsterdam missing SO_2 data were predicted by four different surrounding stations. Correlations between the city station and the surrounding stations for the daily SO_2 mean were very high (0·91–0·92). Missing NO_2 data were predicted by three surrounding stations. The correlation between the city station and the surrounding stations for the NO_2 daily mean ranged from 0·51–0·76. Missing O_3 data were predicted by the city station. The correlation between the city station and the suburban station for the 8 hour maximum O_3 value was 0·85. BS was not measured in the city station but in a station about 20 km west of Amsterdam. There was no other surrounding station which could predict the missing values of this BS station.

In Rotterdam, missing SO_2 data were predicted by up to five different surrounding stations (correlations of SO_2 daily mean between the surrounding stations and the city station ranged from 0·77–0·85). Missing NO_2 data were predicted by four different surrounding stations. The correlation of the NO_2 daily mean between the city station and the surrounding stations ranged from 0·73–0·85. Missing O_3 data were predicted by up to three surrounding stations (correlations of 8 hour maximum with the suburban station from 0·87–0·95) and missing BS data were predicted by two surrounding stations (correlations with the city station were 0·74 and 0·77).

Sometimes a city station did not measure a particular air pollution component for a long period of time. In this case measurements were replaced by those from a nearby station while taking care not to introduce any systematic error.

METEOROLOGICAL DATA

Temperature and humidity were measured daily at and by the Royal Dutch Meteorological Institute in De Bilt, which is situated in the centre of The Netherlands (about 50 km from both Amsterdam and Rotterdam).

INFLUENZA DATA

The incidence of influenza was available on a weekly basis for the whole period of the study except for the summers of 1987, 1988, and 1989[22] when no influenza epidemic occurred. To avoid missing values, these figures were estimated using the mean of the previous summers and a time trend.

HOSPITAL ADMISSION DATA

Data on hospital admissions come from the National Medical Registration, which was almost complete for The Netherlands for the entire period of investigation. In addition to diagnosis, gender, age, and day of admission, place of residence was also recorded. For these analyses, admissions for all patients whose place of residence was Amsterdam or Rotterdam were selected.

The following diagnosis groups of emergency hospital admissions for respiratory diseases, registered on a daily basis, were used: respiratory admissions (ICD-9: 460–519), chronic obstructive pulmonary disease (COPD) admissions (ICD-9: 490–492, 494, 496), and asthma admissions (ICD-9: 493). According to priority rules decided on in the APHEA project, in this study the age groups 15–64 years and ≥65 year were analysed for the respiratory admissions, and the all age groups for COPD and asthma admissions.

STATISTICAL METHODS

Data were analysed following the procedure developed during the APHEA project as described in Katsouyanni *et al.*[23 24] This procedure started with the construction of a "core" model in which the possible confounders of the short term relationship of air pollutants and daily emergency hospital admissions were investigated. In this core model very long term (trend), long term (year, season), mid-term (influenza) to short term systematic (day of the week, holidays), to short term less systematic (meteorology) variables were introduced. Decisions about the model were taken using linear regression on the logarithmically transformed daily admission data. Since all diagnostic groups showed days with no admissions, one admission was added for every day. The significance of each variable was assessed by appropriate F tests.

In examining the seasonal and other chronological variables, linear and quadratic time trends, trigonometric cycles with periods from two years to two months, dummy variables for year, dummy variables for the day of the week and dummy variables for the various holidays were checked.

The incidence of influenza on a daily basis was estimated by assuming that the incidence on each day of the week was the same. An epidemic was defined as a weekly incidence of 20 new cases/week/10 000 persons or more. In the analysis, influenza was included as a dummy variable and lags up to 15 days were examined. However, if not all influenza epidemics could be well controlled for using only one dummy for all epidemics, every epidemic was treated as a separate variable and the real incidence values during the epidemic were used, allowing for a more flexible modelling of each epidemic.

The meteorological variable, temperature, was introduced by checking in the regression analysis linear, quadratic, and cubic terms. Lag 0, lag 1, and the means of lag 0–1 and lag 0–2 were investigated. When the best lag was found, temperature was divided into two continuous variables: one having the temperature values below a certain degree and zero otherwise, and one having the values above this degree and zero otherwise. Degrees from −10 to 20 were checked with these two temperature variables. If a better model was found, this model was investigated further with linear, quadratic, and cubic terms. Next, the humidity variable was introduced by checking in the regression analysis linear, quadratic, and cubic terms with the same lag as temperature. Finally the interaction between temperature and humidity, as defined by the previous steps, was examined. To examine if there was any periodicity left in the core model, a spectral analysis was performed on the residuals of the final model. Any remaining periodicity was filtered out by using relevant interaction terms (that is, day of the week × trend).

In the next stage, the air pollutants lagged up to 2 days and not lagged were alternatively introduced in the found core model. Also, the means of lag 0–1, lag 0–2, and lag 0–3 were investigated. For O_3, lag 0–4 and lag 0–5 were also examined since O_3 can trigger some inflammatory process which may take some days to express itself. The best model was the model with the highest adjusted R^2. The residuals of this model were examined for autocorrelation. For each air pollution component, two models were examined – untransformed and log transformed.

Finally, the best models were repeated using Poisson regression models allowing for overdispersion[25 26] with and without autoregressive terms.

To analyse the separate effects in summer and winter, a dummy variable for the winter and its interaction with the pollutant was included in the model together with the interaction of a dummy variable for the summer with the pollutant. Winter was defined as November to April and summer May to October. In the same way, the effects at levels of other pollutants were assessed using dummy variables indicating levels of air pollution below a cut off point. High and low dummy variables were constructed on the following cut off points (according to the APHEA protocol): 100 μg/m^3 for SO_2–24 h and BS–24 h; 125 μg/m^3 for SO_2–1 h; 120 μg/m^3 for NO_2–1 h; and 80 μg/m^3 for NO_2–24 h. In Amsterdam BS–24 h never exceeded 100 μg/m^3 and 70 μg/m^3 was used as a cut off point. The following synergy effects were examined: SO_2–1 h and –24 h at low/high levels of BS–24 h; BS–24 h at low/high levels of SO_2–24 h; NO_2–24 h; SO_2–1 h; and NO_2–1 h. The lag, on the basis of which the dummy variables were constructed, depended on the city, the type of admission, the age group, and the air pollution parameter considered.

Results

LEVELS OF AIR POLLUTION IN AMSTERDAM AND ROTTERDAM

In The Netherlands, air pollution is at a rather low level. Table 1 shows the levels of air pollution (in μg/m^3) in Amsterdam and Rotterdam. The table shows the mean, median, 5th and 95th centiles, and number of days with non-missing values in relation to season.

O_3 showed a clear seasonal pattern in both cities – it was high in summer and low in winter. The 95th centile of O_3–8 h exceeded 150 μg/m^3 in both Amsterdam and Rotterdam; occasionally the 200 μg/m^3 limit was exceeded especially in the first years of the study period 1977–89. SO_2 showed the reverse seasonal pattern – high levels in winter and low levels in summer. At the beginning of 1979 and the end of 1981 there were peaks in SO_2–24 h exceeding 250 μg/m^3. In 1988 and 1989, SO_2 levels became very low, in winter even below 100 μg/m^3. NO_2 did not show such a clear seasonal variation and the NO_2–24 h value never exceeded 150 μg/m^3 in either city. BS data are available for only four years (1986–89). Again, a seasonal pattern was seen in Amsterdam; the BS–24 h was twice as high in winter. The BS

Table 1 Summer (May–October) and winter (November–April) levels of air pollutants (μg/m³) in Amsterdam and Rotterdam, 1977–89

	Amsterdam			Rotterdam		
	Winter	Summer	Total	Winter	Summer	Total
O_3–8 h						
Mean	53	86	69	45	81	64
Median	55	82	69	44	75	61
5th centile	3	28	5	3	25	6
95th centile	104	152	134	96	159	140
No	1644	1632	3276	1844	2084	3928
O_3–maximum 1 h						
Mean	62	97	79	54	96	76
Median	64	91	77	56	86	71
5th centile	5	42	10	6	36	11
95th centile	114	173	151	106	186	164
No	1644	1632	3276	1844	2084	3928
SO_2–24 h						
Mean	37	20	28	50	31	40
Median	27	17	21	41	26	32
5th centile	5	2	3	8	4	5
95th centile	103	47	75	119	72	97
No	1999	2254	4253	2086	2336	4422
SO_2–maximum 1 h						
Mean	80	52	65	113	86	99
Median	59	41	50	98	70	82
5th centile	15	6	9	20	9	12
95th centile	206	129	167	258	217	240
No	1999	2254	4253	2086	2336	4422
NO_2–24 h						
Mean	52	48	50	57	51	54
Median	51	48	50	55	49	52
5th centile	21	18	19	32	27	29
95th centile	87	81	84	89	83	86
No	1969	2047	4016	2161	2311	4472
NO_2–maximum 1 h						
Mean	74	76	75	83	81	82
Median	71	75	75	78	76	78
5th centile	32	31	31	50	44	46
95th centile	121	134	127	134	140	138
No	1969	2047	4016	2161	2311	4472
BS–24 h						
Mean	14	8	11	28	24	26
Median	8	5	6	23	22	22
5th centile	2	1	1	6	5	6
95th centile	50	24	37	72	54	61
No	523	526	1049	556	683	1239
De Bilt	*Temperature*			*Humidity*		
Mean	4·56	14·35	9·62	84·1	79·37	81·65
Median	5	14·4	10·1	86	80	83
5th centile	−3·57	8·3	−1·37	66	62	64
95th centile	11·3	20·6	19·1	97	92	95
No	2205	2361	4566	2205	2361	4566

levels were higher in Rotterdam in both summer and in winter. In Rotterdam the BS–24 h occasionally exceeded 100 μg/m³. The two meteorological variables, temperature and humidity, reflected the rather moderate and damp climate in The Netherlands. Visual inspection of the data showed that the climate was rather stable over these 13 years – there were no heat waves nor very cold periods.

EMERGENCY HOSPITAL ADMISSIONS

The absolute daily counts of the emergency hospital admissions due to diseases of the respiratory system in Amsterdam and Rotterdam were low. Table 2 shows the counts for the three diagnostic groups of this study in relation to city and the age groups 0–14, 15–64, 65+, and all ages. Hospital admissions for respiratory diseases did not show clear differences between

Table 2 Daily count of hospital emergency admissions for the respiratory system (ICD 9 groups) in Amsterdam and Rotterdam

Age group	Amsterdam			Rotterdam		
	Respiratory (460–519)	COPD (490–492,494,496)	Asthma (493)	Respiratory (460–519)	COPD (490–492,494,496)	Asthma (493)
All ages						
Mean	6·70	1·74	1·13	4·79	1·57	0·53
Median	6·29	1·11	1·01	4·24	1·06	0·00
Minimum	0·00	0·00	0·00	0·00	0·00	0·00
Maximum	23·00	9·00	7·00	19·00	9·00	5·00
0–14 y						
Mean	2·23	0·29	0·32	1·13	0·07	0·20
Median	2·02	0·00	0·00	1·01	0·00	0·00
Minimum	0·00	0·00	0·00	0·00	0·00	0·00
Maximum	11·00	4·00	4·00	9·00	2·00	3·00
15–64 y						
Mean	2·12	0·44	0·61	1·59	0·49	0·26
Median	2·02	0·00	0·00	1·06	0·00	0·00
Minimum	0·00	0·00	0·00	0·00	0·00	0·00
Maximum	11·00	6·00	5·00	8·00	5·00	4·04
65+ y						
Mean	2·35	1·00	0·20	2·06	1·01	0·06
Median	2·05	1·01	0·00	2·02	1·01	0·00
Minimum	0·00	0·00	0·00	0·00	0·00	0·00
Maximum	10·00	7·00	3·00	13·00	8·00	2·00

Table 3 Parameter estimates for core model variables from a Poisson model without autoregression (Amsterdam respiratory 65+)

Variable	Regression coefficient	SEM	95% confidence interval	
			Lower	Upper
Intercept	2·522246633	1·2758311885	0·0209498569	5·0235434091
Linear trend	−0·000422635	0·0002845072	−0·0009804181	0·0001351
Year '77	−2·370852558	1·245771053	−4·8132157382	0·0715106
Year '78	−1·883029747	1·1429638867	−4·1238370812	0·3577776
Year '79	−1·704983342	1·0390895108	−3·7421425422	0·3321759
Year '80	−1·589230233	0·9349352326	−3·422192544	0·2437321
Year '81	−1·543484461	0·8316173113	−3·1738895795	0·0869207
Year '82	−1·172874839	0·7272588144	−2·5986826921	0·252933
Year '83	−1·052565169	0·6244555409	−2·2768248092	0·1716945
Year '84	−1·03491517	0·5208657482	−2·0560846071	−0·013746
Year '85	−0·771917643	0·4175147781	−1·5904650952	0·0466298
Year '86	−0·654141581	0·3146018706	−1·2709258794	−0·037357
Year '87	−0·565462791	0·2128311313	−0·9827231836	−0·148202
Year '88	−0·209357752	0·1137739841	−0·4324142988	0·0136988
Year '89	Reference category			
Sin 1 y	0·06727121	0·038633805	−0·0084712651	0·1430137
Cos 1 y	0·177883657	0·0279400725	0·1231064934	0·2326608
Sin $\frac{1}{2}$ y	−0·063276774	0·0227591898	−0·1078966962	−0·018657
Cos $\frac{1}{2}$ y	0·043150227	0·0150500957	0·0136441633	0·0726563
Sin $\frac{1}{3}$ y	0·010445425	0·0181335819	−0·0251058849	0·0459967
Cos $\frac{1}{3}$ y	−0·023832263	0·0141919004	−0·0516558147	0·0039913
Sin $\frac{1}{4}$ y	0·005447888	0·0165249717	−0·0269497045	0·0378455
Cos $\frac{1}{4}$ y	0·03963122	0·0143036937	0·0115884954	0·0676739
Sin $\frac{1}{5}$ y	−0·057744894	0·0158129061	−0·0887464645	−0·026743
Cos $\frac{1}{5}$ y	0·020123651	0·0142830901	−0·0078786803	0·048126
Sin $\frac{1}{6}$ y	−0·032022307	0·0153792658	−0·062173716	−0·001871
Cos $\frac{1}{6}$ y	0·025628417	0·0141829104	−0·002177509	0·0534343
Influenza lag 1	0·292335489	0·0366282062	0·2205250372	0·3641459
Monday	0·790357101	0·0415468906	0·7089034542	0·8718107
Tuesday	0·579021434	0·0430424674	0·4946356737	0·6634072
Wednesday	0·649201967	0·0425263708	0·5658280261	0·7325759
Thursday	0·620280444	0·0427430789	0·5364816413	0·7040792
Friday	0·736702647	0·0419114568	0·6545342594	0·818871
Saturday	0·077291695	0·0478202689	−0·0164610561	0·1710444
Sunday	Reference category			
Temperature mean lag 0–1	−0·000430998	0·0007120325	−0·0018269541	0·000965
Humidity mean lag 0–1, linear	−0·003031371	0·0019153719	−0·0067865023	0·0007238
Temperature × humidity	0·000014378	0·0000097077	−0·0000046545	0·0000334

the different age groups in Amsterdam, but in Rotterdam there seemed to be an increasing trend with age. The admissions for COPD were clearly most frequent in the older age group and admissions for asthma were most frequent in the younger and middle age groups. Overall, there seemed to be no difference in emergency hospital admissions due to respiratory diseases in Rotterdam and in Amsterdam.

"CORE" MODELS

Core models were built according to the APHEA protocol for every age-city-diagnostic group. Table 3 shows the core model (re-

Table 4 Relative risks (RR) for a 100 µg/m³ increase in air pollution parameters in Amsterdam and Rotterdam

Pollutant		Respiratory admissions						COPD admissions			Asthma admissions		
		Age 65+			Age 15–64 y			All ages			All ages		
		Lag	RR	(95% CI)	Lag	RR	(95% CI)	Lag	RR	(95% CI)	Lag	RR	(95% CI)
(A) Amsterdam													
O_3–8 h maximum	One day	1	1·060	(0·059, 1·172)	1	1·001	(0·903, 1·111)	0	1·039	(0·924, 1·168)	1	1·090	(0·934, 1·272)
	Cumulative	0–1	1·062	(0·945, 1·195)	0–2	1·012	(0·885, 1·156)	0–3	1·156	(0·982, 1·361)	0–1	1·154	(0·951, 1·399)
O_3–1 h maximum	One day	1	1·071	(0·977, 1·173)	1	0·999	(0·910, 1·097)	0	1·017	(0·915, 1·130)	1	1·055	(0·917, 1·213)
	Cumulative	0–1	1·089	(0·975, 1·217)	0–2	0·991	(0·874, 1·125)	0–3	1·117	(0·957, 1·304)	0–2	1·085	(0·905, 1·302)
SO_2–daily mean	One day	2	1·046	(0·965, 1·134)	2	0·944	(0·864, 1·032)	0	0·907	(0·814, 1·011)	1	0·802	(0·696, 0·924)
	Cumulative	0–3	1·008	(0·899, 1·131)	0–3	0·915	(0·809, 1·035)	0–1	0·948	(0·838, 1·072)	0–3	0·792	(0·654, 0·958)
SO_2–1 h maximum	One day	2	1·022	(0·985, 1·060)	2	0·989	(0·952, 1·028)	0	0·978	(0·933, 1·026)	2	0·995	(0·942, 1·051)
	Cumulative	0–3	1·010	(0·955, 1·068)	0–2	0·977	(0·927, 1·030)	0–1	0·995	(0·940, 1·053)	0–3	0·941	(0·863, 1·026)
NO_2–daily mean	One day	2	1·023	(0·907, 1·154)	1	0·890	(0·783, 1·012)	1	0·937	(0·814, 1·079)	2	1·062	(0·887, 1·271)
	Cumulative	0–3	1·014	(0·854, 1·204)	0–3	0·858	(0·715, 1·029)	0–3	0·795	(0·649, 0·975)	0–2	0·902	(0·715, 1·139)
NO_2–1 h maximum	One day	2	0·996	(0·918, 1·080)	1	0·894	(0·821, 0·973)	1	0·948	(0·863, 1·041)	2	1·035	(0·918, 1·166)
	Cumulative	0–3	0·980	(0·870, 1·104)	0–3	0·860	(0·761, 0·973)	0–3	0·852	(0·742, 0·978)	0–2	0·931	(0·792, 1·094)
BS-daily mean	One day	2	1·081	(0·757, 1·543)	2	0·869	(0·579, 1·304)	0	1·131	(0·734, 1·744)	0	0·802	(0·435, 1·478)
	cumulative	0–3	1·132	(0·687, 1·867)	0–1	1·187	(0·754, 1·868)	0–3	1·466	(0·812, 2·647)	0–2	0·638	(0·291, 1·398)

		Respiratory admissions												COPD admissions		
		Age 65+ 1977–1981			Age 65+ 1982–1984			Age 65+ 1985–1989			Age 15–64			All ages		
		Lag	RR	(95% CI)	Lag	RR	(95% CI)	Lag	RR	(95% CI)	Lag	RR	(95% CI)	Lag	RR	(95% CI)
(B) Rotterdam																
O_3–8 h	One day	2	1·248	(1·039, 1·499)	1	0·927	(0·745, 1·154)	0	1·044	(0·882, 1·235)	0	0·998	(0·888, 1·122)	2	1·039	(0·921, 1·171)
maximum	Cumulative	0–5	1·169	(0·879, 1·554)	0–1	0·965	(0·739, 1·261)	0–5	1·039	(0·790, 1·367)	0–5	1·152	(0·965, 1·377)	0–4	1·018	(0·850, 1·221)
O_3–1 h	One day	2	1·272	(1·089, 1·487)	1	0·976	(0·815, 1·168)	0	1·005	(0·872, 1·159)	0	1·044	(0·948, 1·151)	2	1·030	(0·931, 1·139)
maximum	Cumulative	0–5	1·126	(0·877, 1·446)	0–1	1.016	(0·813, 1·269)	0–5	0·956	(0·747, 1·224)	0–5	1·152	(0·986, 1·346)	0–4	1·035	(0·886, 1·208)
SO_2–daily	One day	2	1·027	(0·904, 1·165)	0	1·087	(0·890, 1·328)	0	1·045	(0·908, 1·204)	1	0·941	(0·855, 1·036)	2	0·963	(0·874, 1·059)
mean	Cumulative	0–3	1·011	(0·834, 1·227)	0–3	1·258	(0·926, 1·710)	0–3	0·968	(0·787, 1·190)	0–2	0·895	(0·787, 1·019)	0–3	1·019	(0·887, 1·172)
SO_2–1 h	On day	0	0·892	(0·842, 0·945)	0	1·005	(0·933, 1·081)	0	1·010	(0·955, 1·068)	1	0·989	(0·953, 1·025)	2	0·991	(0·955, 1·029)
maximum	Cumulative	0–3	0·987	(0·907, 1·074)	0–3	1·062	(0·938, 1·202)	0–1	1·064	(0·992, 1·141)	0–2	0·965	(0·915, 1·018)	0–3	1·013	(0·953, 1·076)
No_2–daily	One day	0	1·342	(0·998, 1·805)	0	1·232	(0·945, 1·606)	0	1·172	(0·990, 1·387)	1	0·965	(0·833, 1·118)	2	1·051	(0·903, 1·223)
mean	Cumulative	0–3	1·093	(0·729, 1·639)	0–1	1·261	(0·928, 1·712)	0–1	1·193	(0·982, 1·451)	0–1	1·024	(0·867, 1·210)	0–1	1·203	(1·011, 1·430)
NO_2–1 h	One day	2	1·154	(0·982, 1·357)	0	1·176	(1·002, 1·381)	1	1·073	(0·970, 1·186)	1	1·036	(0·951, 1·129)	2	1·166	(1·070, 1·271)
maximum	Cumulative	0–3	1·021	(0·800, 1·304)	0–1	1·246	(1·031, 1·504)	0–1	1·093	(0·971, 1·230)	0–1	1·075	(0·972, 1·189)	0–1	1·196	(1·079, 1·326)
BS–daily	One day							2	0·969	(0·787, 1·193)	0	1·374	(1·091, 1·730)	2	0·929	(0·724, 1·192)
mean	Cumulative							0–2	1·094	(0·836, 1·431)	0–3	1·383	(0·991, 1·932)	0–3	1·241	(0·876, 1·757)

Table 5 Relative risks (RR) for a 100 μg/m³ increase in air pollution parameters, effects by season

Pollutant			*Respiratory admissions*				*COPD admissions*		*Asthma admissions*	
			Age 65+y		*Age 15–64y*		*All ages*		*All ages*	
			RR	*(95% CI)*	*RR*	*(95% CI)*	*RR*	*(95% CI)*	*RR*	*(95% CI)*
(A) Amsterdam										
O_3–8 h maximum	One day	S	1·127	(0·983, 1·292)	0·964	(0·852, 1·091)	1·079	(0·933, 1·249)	1·009	(0·823, 1·237)
		W	0·996	(0·869, 1·142)	1·053	(0·920, 1·205)	0·995	(0·853, 1·160)	1·194	(0·961, 1·483)
	Cumulative	S	1·147	(0·976, 1·348)	0·984	(0·843, 1·148)	1·241	(1·014, 1·518)	1·145	(0·891, 1·471)
		W	0·990	(0·848, 1·156)	1·050	(0·888, 1·242)	1·080	(0·884, 1·319)	1·168	(0·895, 1·525)
O_3–1 h maximum	One day	S	1·109	(0·987, 1·247)	0·976	(0·876, 1·088)	1·049	(0·923, 1·193)	0·995	(0·834, 1·186)
		W	1·021	(0·895, 1·166)	1·038	(0·912, 1·182)	0·972	(0·838, 1·127)	1·154	(0·934, 1·425)
	Cumulative	S	1·138	(0·985, 1·316)	0·975	(0·845, 1·126)	1·206	(0·996, 1·460)	1·093	(0·869, 1·375)
		W	1·037	(0·891, 1·207)	1·017	(0·865, 1·196)	1·032	(0·851, 1·253)	1·079	(0·830, 1·403)
SO_2–daily mean	One day	S	1·215	(0·963, 1·532)	0·964	(0·767, 1·211)	0·911	(0·713, 1·164)	1·034	(0·761, 1·406)
		W	1·030	(0·946, 1·121)	0·942	(0·859, 1·034)	0·907	(0·807, 1·019)	0·759	(0·648, 0·888)
	Cumulative	S	1·002	(0·707, 1·421)	0·934	(0·666, 1·309)	0·869	(0·644, 1·174)	1·507	(0·946, 2·398)
		W	1·007	(0·897, 1·131)	0·914	(0·806, 1·037)	0·960	(0·844, 1·092)	0·728	(0·594, 0·891)
SO_2–1 h maximum	One day	S	1·058	(0·989, 1·131)	1·025	(0·960, 1·094)	0·982	(0·907, 1·064)	1·076	(0·989, 1·172)
		W	1·009	(0·968, 1·053)	0·975	(0·932, 1·020)	0·977	(0·923, 1·033)	0·953	(0·890, 1·020)
	Cumulative	S	1·029	(0·919, 1·151)	1·011	(0·917, 1·115)	1·002	(0·907, 1·106)	1·164	(1·008, 1·344)
		W	1·005	(0·947, 1·067)	0·967	(0·911, 1·026)	0·993	(0·931, 1·059)	0·866	(0·783, 0·959)
NO_2–daily mean	One day	S	1·028	(0·862, 1·227)	0·870	(0·730, 1·037)	0·932	(0·767, 1·133)	1·140	(0·889, 1·462)
		W	1·015	(0·867, 1·188)	0·911	(0·765, 1·085)	0·942	(0·779, 1·140)	0·991	(0·772, 1·272)
	Cumulative	S	1·056	(0·811, 1·377)	0·851	(0·658, 1·100)	0·840	(0·631, 1·119)	0·965	(0·689, 1·351)
		W	0·982	(0·791, 1·219	0·867	(0·683, 1·099)	0·760	(0·583, 0·991)	0·853	(0·624, 1·167)
NO_2–1 h maximum	One day	S	0·976	(0·875, 1·088)	0·911	(0·818, 1·016)	0·962	(0·852, 1·085)	1·027	(0·880, 1·198)
		W	1·017	(0·907, 1·142)	0·870	(0·766, 0·988)	0·929	(0·808, 1·068)	1·046	(0·874, 1·251)
	Cumulative	S	0·966	(0·825, 1·132)	0·906	(0·773, 1·061)	0·904	(0·756, 1·081)	0·931	(0·755, 1·147)
		W	0·993	(0·844, 1·167)	0·810	(0·680, 0·964)	0·791	(0·649, 0·963)	0·931	(0·736, 1·177)
BS daily mean	One day	S	1·029	(0·441, 2·403)	0·984	(0·410, 2·362)	0·665	(0·280, 1·576)	1·108	(0·354, 3·468)
		W	1·091	(0·738, 1·611)	0·847	(0·534, 1·343)	1·384	(0·838, 2·284)	0·718	(0·351, 1·472)
	Cumulative	S	0·927	(0·257, 3·339)	0·971	(0·357, 2·643)	0·956	(0·269, 3·398)	1·624	(0·327, 8·071)
		W	1·169	(0·683, 2·002)	1·273	(0·758, 2·139)	1·664	(0·859, 3·225)	0·492	(0·202, 1·198)

			Respiratory admissions								*COPD admissions*	
			Age 65+ 1977–81		*Age 65+ 1982–84*		*Age 65+ 1985–89*		*Age 15–64*		*All ages*	
			RR	*(95% CI)*	*RR*	*(95% CI)*	*RR*	*(95% CI)*	*RR*	*(95% CI)*	*RR*	*(95% CI)*
(B) Rotterdam												
O_2–8 h maximum	One day	S	1·344	(1·097, 1·647)	0·950	(0·792, 1·139)	1·050	(0·920, 1·199)	0·996	(0·896, 1·106)	1·031	(0·898, 1·183)
		W	1·037	(0·769, 1·399)	1·019	(0·787, 1·320)	1·019	(0·857, 1·212)	0·959	(0·835, 1·103)	1·056	(0·881, 1·267)
	Cumulative	S	1·265	(0·927, 1·726)	0·995	(0·801, 1·234)	1·079	(0·879, 1·325)	1·083	(0·927, 1·265)	1·029	(0·842, 1·258)
		W	0·978	(0·643, 1·488)	1·050	(0·773, 1·427)	1·009	(0·779, 1·308)	1·093	(0·904, 1·322)	0·996	(0·771, 1·287)
O_3–1 h maximum	One day	S	1·346	(1·133, 1·598)	0·985	(0·850, 1·142)	1·024	(0·918, 1·144)	1·026	(0·940, 1·120)	1·038	(0·927, 1·163)
		W	1·085	(0·830, 1·419)	1·050	(0·835, 1·321)	1·000	(0·853, 1·172)	1·013	(0·894, 1·148)	1·008	(0·855, 1·188)
	Cumulative	S	1·213	(0·921, 1·599)	1·029	(0·862, 1·230)	1·013	(0·841, 1·220)	1·098	(0·956, 1·260)	1·043	(0·881, 1·236)
		W	0·952	(0·653, 1·387)	1·070	(0·812, 1·409)	0·942	(0·745, 1·191)	1·103	(0·930, 1·307)	1·010	(0·801, 1·275)
SO_2–daily mean	One day	S	1·140	(0·883, 1·472)	1·107	(0·848, 1·446)	1·079	(0·900, 1·295)	1·057	(0·924, 1·211)	1·104	(0·923, 1·319
		W	0·991	(0·859, 1·145)	1·041	(0·862, 1·257)	0·997	(0·887, 1·121)	0·932	(0·854, 1·017)	0·920	(0·824, 1·027)
	Cumulative	S	1·009	(0·674, 1·510)	1·308	(0·866, 1·978)	0·900	(0·674, 1·201)	1·067	(0·888, 1·282)	1·110	(0·847, 1·457)
		W	0·999	(0·808, 1·235)	1·113	(0·838, 1·478)	0·965	(0·820, 1·134)	0·888	(0·793, 0·995)	0·999	(0·858, 1·163)
SO_2–1 h maximum	One day	S	0·818	(0·748, 0·896)	1·002	(0·927, 1·084)	1·030	(0·971, 1·094)	1·024	(0·982, 1·068)	1·032	(0·978, 1·089)
		W	0·946	(0·881, 1·016)	1·007	(0·928, 1·092)	0·985	(0·936, 1·037)	0·971	(0·935, 1·009)	0·961	(0·915, 1·009)
	Cumulative	S	0·957	(0·832, 1·100)	1·058	(0·926, 1·208)	1·065	(0·986, 1·150)	1·015	(0·954, 1·080)	1·067	(0·974, 1·168)
		W	1·003	(0·905, 1·111)	1·014	(0·887, 1·160)	1·005	(0·944, 1·070)	0·949	(0·900, 1·001)	0·981	(0·912, 1·055)
NO_2–daily mean	One day	S	1·448	(0·973, 2·153)	1·226	(0·898, 1·676)	1·086	(0·911, 1·293)	1·022	(0·864, 1·208)	1·065	(0·855, 1·327)
		W	1·208	(0·800, 1·826)	1·072	(0·818, 1·404)	1·082	(0·920, 1·273)	0·968	(0·824, 1·138)	1·036	(0·848, 1·265)
	Cumulative	S	1·100	(0·635, 1·905)	1·308	(0·912, 1·876)	1·053	(0·855, 1·296)	1·090	(0·900, 1·322)	1·139	(0·882, 1·470)
		W	1·026	(0·579, 1·821)	1·073	(0·786, 1·466)	1·137	(0·945, 1·367)	0·985	(0·820, 1·183)	1·248	(0·993, 1·569)
NO_2–1 h maximum	One day	S	1·171	(0·958, 1·432)	1·108	(0·931, 1·317)	0·975	(0·879, 1·083)	1·060	(0·965, 1·163)	1·146	(1·018, 1·290)
		W	1·109	(0·855, 1·439)	1·096	(0·917, 1·310)	1·092	(0·991, 1·204)	1·001	(0·905, 1·107)	1·184	(1·049, 1·337)
	Cumulative	S	0·984	(0·724, 1·337)	1·161	(0·945, 1·426)	1·004	(0·888, 1·135)	1·120	(1·004, 1·250)	1·172	(1·019, 1·349)
		W	1·042	(0·703, 1·542)	1·146	(0·932, 1·409)	1·065	(0·947, 1·196)	1·001	(0·888, 1·127)	1·217	(1·051, 1·409)
BS–daily mean	One day	S					0·919	(0·726, 1·164)	1·307	(1·000, 1·708)	0·964	(0·653, 1·422)
		W					1·022	(0·852, 1·226)	1·129	(0·904, 1·409)	0·903	(0·666, 1·225)
	Cumulative	S					0·946	(0·691, 1·295)	1·460	(0·981, 2·174)	1·304	(0·727, 2·339)
		W					1·100	(0·872, 1·387)	1·129	(0·829, 1·538)	1·193	(0·785, 1·813)

S = summer; W = winter.

gression coefficients, SEM, and the 95% confidence intervals (95% CI) from a Poisson model) of the respiratory emergency hospital admissions of inhabitants of Amsterdam age 65 years and older. These core models were different for different age, diagnosis, and city groups. The respiratory admissions in Rotterdam (age group 65+) clearly showed three periods with a different variability in the number of admissions. Some difference in hospital policy may have created this. In the other age groups or diagnostic groups in Rotterdam this was not so clear. Filtering was not successful and three different models for the three periods (1977–81, 1982–84, 1985–89) were built. A spectral analysis confirmed that the residual series of all the core models were not different from white noise.

RELATION BETWEEN AIR POLLUTION AND EMERGENCY HOSPITAL ADMISSIONS

Table 4A and B shows the relative risks (RR) of a 100 μg/m³ increase in air pollution parameters on hospital admissions in Amsterdam and Rotterdam. The chosen lag for the one day measurement is also indicated in these tables as well as the chosen average of lagged days to indicate the effect of cumulative exposure for the various air pollutants.

In Amsterdam (table 4A), O_3 showed positive non-significant effects on the daily number of hospital admissions for all age-diagnosis groups (RR for the 8-h maximum range from 1·001–1·156). This means a negative effect on health; the higher the O_3, the more admissions. SO_2 had a positive effect on the number of respiratory admissions in the 65+ age group (RR

Table 6 The Netherlands – relative risks (RR) for a 100 µg/m³ increase in air pollution parameters, effects by season

		Respiratory admissions all ages	
		RR	(95% CI)
O_3–8 h maximum lag 2	Summer	1·069	(1·043, 1·096)
	Winter	0·974	(0·948, 1·001)
O_3–1 h maximum lag 2	Summer	1·051	(1·029, 1·073)
	Winter	0·976	(0·951, 1·002)
SO_2–daily mean lag 2	Summer	1·070	(0·999, 1·146)
	Winter	1·028	(1·008, 1·048)
SO_2–1 h maximum lag 2	Summer	1·029	(1·001, 1·059)
	Winter	1·017	(1·005, 1·029)
NO_2–daily mean lag 0	Summer	1·034	(0·979, 1·092)
	Winter	1·082	(1·042, 1·122)
NO_2–1 h maximum lag 0	Summer	1·017	(0·983, 1·051)
	Winter	1·057	(1·027, 1·088)
BS–daily mean lag 2	Summer	1·083	(0·940, 1·247)
	Winter	1·101	(1·024, 1·184)

range from 1·010–1·046). In the other age and diagnostic groups, SO_2 had a negative effect (RR from 0·802–0·995). This negative effect reached significance where asthma admissions were concerned. NO_2 had negative effects on the number of admissions in the 15–64 age group for respiratory admissions (RR 0·858–0·894) and on the number of COPD admissions for all ages (RR 0·795–0·948). This negative effect was sometimes significant. The number of respiratory admissions in the 65+ age group and the number of admissions due to asthma were not clearly influenced by NO_2 (RR 0·902–1·062). Black smoke also showed mixed results (RR 0·638–1·466). It was mostly in the older age group that positive effects were found (RR 1·081 (95% CI 0·757, 1·543) for the one day measure and 1·132 (0·687, 1·867) for the cumulative measure).

In Rotterdam (table 4B) respiratory admissions in the older age group are listed for three periods: 1977–81, 1982–84, and 1985–89 (as mentioned before). Asthma admissions are not listed here. Again, O_3 had a mainly positive influence with RR ranging from 0·927–1·248. SO_2 showed the same mixed results as in Amsterdam: mainly positive effects on admissions in the older age group (RR 0·892–1·258) and mainly negative effects in the other groups (RR 0·895–1·019). NO_2 and BS now also showed predominantly positive influences on the number of admissions (RR 0·929–1·383).

Table 5A and B shows the RR of a 100 µg/m³ increase in air pollution parameters on hospital admissions in Amsterdam and Rotterdam in relation to season. The effect modification of season was very inconsistent in Amsterdam (table 5A). Again, only in the older age group were the expected effects found: the effect of O_3 was higher during the summer and that of BS was higher in the winter. Rotterdam (table 5B) showed the same mixed results. The effect of O_3 on respiratory admissions in the summer was significant for the period 1977–81 in the older age group.

The analyses on the synergistic effect of pollutants at levels of other pollutants did not significantly change the results of the models without these interactions.

Discussion

In recent years many studies have reported the relations between daily variations in exposure to the major air pollutants O_3, particulate matter, and SO_2 and increasing hospital admissions. Pönkä[4] showed the effect of low O_3 concentrations (0–90 µg/m³) on hospital admissions for asthma in Helsinki. Thurston *et al.*[10 11] found that asthma admissions were related to O_3 in Toronto, even when all days with concentrations exceeding 240 µg/m³ were removed from the analysis. Schwartz[5–8] showed relations between O_3 and hospital admissions for the elderly. In The Netherlands, Brunekreef *et al.*[14] showed that in healthy young men exercising outdoors, O_3 was related to lung function changes and acute respiratory symptom changes at low levels of exposure to O_3, even if observations with O_3 concentrations higher than 120 µg/m³ were removed from the analysis. Our results do not contradict these results. Although the effects of O_3 were mostly not significant, O_3 had a consistently adverse effect on respiratory health and this effect was mostly found in summer, when the O_3 concentrations were higher.

Many papers[3–17] showed relations between the other pollutants and respiratory health at relatively low levels of these pollutants. The results of the analyses in this paper do not always agree with those findings. SO_2 did not show any clear effects; in Amsterdam a significant positive effect on health was even found. The same is true for NO_2 in Amsterdam; in Rotterdam, however, significant negative effects of NO_2 on health were found. BS did not show any clear effects in Amsterdam; in Rotterdam it was negatively but not significantly related to health. Why do these results not always agree with those in other published reports? Perhaps the way we controlled for seasonal and other chronological variables or other possible confounders was inadequate. It is possible that overfiltering took place. Overfiltering will unnecessarily reduce the power of the analyses and will be more severe if cumulative exposure over several days is necessary to produce hospitalisation effects.[26] A second explanation may be the low level of the pollutants: the annual mean (range) of O_3–8 h is 69 (0–252) µg/m³ in Amsterdam and 64 (0–286) µg/m³ in Rotterdam. The annual mean of SO_3–24 h is 28 (0–381) µg/m³ in Amsterdam and 40 (0–379) µg/m³ in Rotterdam. For NO_2–24 h, the annual mean is 50 (2–133) µg/m³ in Amsterdam and 54 (7–146) µg/m³ in Rotterdam. The annual mean of BS–24 h is 11 (1–84) µg/m³ in Amsterdam and 26 (1–144) µg/m³ in Rotterdam.

The levels of SO_2, NO_2, and BS were lower than the levels in most cities in the studies mentioned above. The O_3 concentration was also lower but closer to the levels examined and this is the pollutant which showed the most consistent results. BS was much higher in Rotterdam than in Amsterdam. It was in Rotterdam that the most consistent results were found. This can be another indication that at these low levels of pollutants no effect on health can be found. However, other authors found effects at the same levels of air pollution as in our study.[4] This can be explained by the number of hospital admissions in Amsterdam and

Rotterdam. The total daily number of emergency admissions in these two cities was low compared with the frequency in most of the other populations. The fact that the expected results were mostly found in the age-diagnosis group with the highest number of daily admissions – that is, total respiratory admissions age 65 and older – could be an indication that the small number of daily hospital admissions might explain the inconsistent results. Results of analyses of data for the whole of The Netherlands, with about 14 million inhabitants and very little spatial variation in air pollution levels, seemed to confirm this in showing results as expected in all cases. In table 6, RR for a 100 μg/m^3 increase in air pollutants on respiratory admissions for all age groups in The Netherlands are given. The RR tended to be smaller than the RR in the two cities, which can be explained by the fact that all ages instead of separate age groups were considered, but they are significant for all pollutants in the season with their highest level – O_3 in summer and the other pollutants in winter.

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