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Air pollution and mortality in the Netherlands: are the elderly more at risk?

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Air pollution and mortality in the Netherlands: are the elderly more at risk? P. Fischer, G. Hoek, B. Brunekreef, A. Verhoeff, J. van Wijnen. ©ERS Journals Ltd 2003.
ABSTRACT: The association between daily mortality and short-term variations in the ambient levels of ozone (O_3), black smoke (BS), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and particulate matter was studied in the Netherlands.

Daily total and cause-specific mortality counts (cardiovascular, chronic obstructive pulmonary disease (COPD) and pneumonia), air quality, temperature, relative humidity and influenza data were obtained from 1986–1994. The relationship between daily mortality and air pollution was modelled using Poisson regression analysis. All pollution mortality associations were adjusted for potential confounding due to long-term trends, seasonal trends, influenza epidemics, ambient temperature, ambient relative humidity, day of the week and holidays, using generalised additive models.

Statistically significant associations were mostly found in the elderly, that is the age categories of 65–74 and ⩾75 yrs for the pollutants PM10 (particles with a 50% cut-off aerodynamic diameter of 10 µm), BS, SO_2, NO_2 and CO. This may partly be due to a better precision of relative risk (RR) estimates for the larger numbers of deaths in these age groups. Significant associations for those <65 yrs were found for O_3 (total and COPD mortality), PM10 (pneumonia), NO_2 (pneumonia) and CO (pneumonia).

RR estimates for deaths between 45–65 yrs tended to be smaller than those in >65 yrs, with the exception of ozone; for cardiovascular mortality the RR for PM10, O_3 and CO were similar in these age groups.

In conclusion, larger relative risks for air pollution were mostly found in the elderly except for ozone and for death-cause pneumonia which showed larger relative risk in younger age groups.
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Associations between outdoor air pollution and effects on both acute and chronic mortality and hospital admissions in the Netherlands have been published recently. VERHOEFF *et al.* [1] studied the association between fluctuations in daily mortality and daily levels of ambient air pollution for the city of Amsterdam from 1987–1992. They reported positive associations between daily total mortality and the daily mean concentrations of particles with a 50% cut-off aerodynamic diameter of 10 µm (PM10), black smoke (BS) and ozone (O_3), but not with carbon monoxide (CO) or sulphur dioxide (SO_2). HOEK *et al.* [2] studied the association between fluctuations in daily mortality and daily levels of ambient air pollution for the city of Rotterdam from 1983–1991. They reported positive associations between daily total mortality and the daily mean concentrations of total suspended particles (TSP), BS and O_3, but not with CO or SO_2. MACKENBACH *et al.* [3] studied the association between daily mortality and SO_2 levels in the Netherlands from 1979–1987. After adjustment for a number of potential confounding factors, no association was found between levels of SO_2 and mortality.

The Air Pollution on Health: a European Approach (APHEA) study has also been conducted in the Netherlands [4]. In Amsterdam (694,700 inhabitants) and Rotterdam (576,200 inhabitants), O_3 had a nonsignificant positive effect on the number of respiratory emergency admissions in summer in people aged ⩾65 yrs (relative risk (RR) for a 100 $\mu g \cdot m^{-3}$ increase in O_3-8 h of 1.123 in Amsterdam and a significant positive effect of 1.34 in Rotterdam (1977–1981)). SO_2 did not show any clear effects; in Amsterdam a significant negative effect was even found. The same was true for nitrogen dioxide (NO_2) in Amsterdam; in Rotterdam, however, NO_2 showed nonsignificant positive effects (RR 0.97 and 1.3 respectively). BS did not show any clear effects in Amsterdam; in Rotterdam it was positively but not significantly related to the number of admissions. The results show that the relationship 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.

In another time-series study in the Netherlands, a strong association between the day-to-day variation in pollen concentrations and that of deaths due to cardiovascular disease, chronic obstructive pulmonary disease (COPD), and pneumonia was found [5].

The association of daily mortality with short-term variations in the ambient concentrations of major gaseous pollutants and particulate matter (PM) in the four major Dutch urban areas was compared with that in the remainder of the country [6]. Daily mortality was significantly associated with the concentration of all air pollutants. An increase in the PM10 concentration by 100 $\mu g \cdot m^{-3}$ was associated with a RR of 1.02 for total mortality. The largest RR were found for pneumonia deaths. Ozone had the most consistent, independent association with mortality. Aerosol sulphate (SO_4^{2-}), nitrate (NO_3-), and BS were more consistently associated with total mortality than was PM10. The RR for all pollutants were substantially larger in the summer months than in the winter months. The RR of total mortality for PM10 was 1.10 for the summer and 1.03 for the winter. There was no consistent difference between RR in the four major urban areas and the more rural areas.

Further, deaths due to heart failure, arrhythmia, cerebrovascular causes, and thrombocytic causes were more strongly associated with air pollution than cardiovascular deaths in general [7]. Heart failure deaths, which made up 10% of all cardiovascular deaths, were found to be responsible for ~30% of the cardiovascular deaths related to PM, SO_2, CO, and NO_2.

Since exposure to ambient air pollution has been estimated mostly as city average concentrations, assuming homogeneous exposure within the city, HOEK *et al.* [8] used an ongoing cohort study, the Netherlands Cohort Study (NLCS) on diet and cancer, to investigate the relationship between traffic-related air pollution and mortality, based on developing methods for exposure assessment and evaluating the contrast in exposure to air pollution within the cohort. Distance to major roads was calculated to characterise local traffic contributions, using a Geographic Information System (GIS). Interpolation resulted in reasonably precise regional background estimation. Urban and local scales contributed significantly to the contrast within the cohort, supporting the use of the estimated concentration at the 1986 address as a relevant exposure variable.

Recently, the results of the analyses of the relationship between mortality and the estimated concentration at the 1986 address were published by HOEK *et al.* [9]. They investigated a random sample of 5,000 people from the full cohort of the NLCS study (age 55–69 yrs) from 1986–1994. The association between exposure to air pollution and (cause specific) mortality was assessed with Cox's proportional hazards models, with adjustment for potential confounders. Four hundred and eighty-nine (11%) of 4,492 people with data died during the follow-up period. Cardiopulmonary mortality was associated with living near a major road (RR 1.95 (95% confidence interval (CI) 1.09–3.52)) and, less consistently, with the estimated ambient background concentration (RR 1.34 (95% CI 0.68–2.64)). The RR for living near a major road was 1.41 (95% CI 0.94–2.12) for total deaths. Noncardiopulmonary, nonlung cancer deaths were unrelated to air pollution (RR 1.03 (95% CI 0.54–1.96) for living near a major road).

Background: studies on air pollution effects among the elderly

Numerous studies have shown associations between daily variations in air pollution and daily mortality [10–15]. Initially these studies were conducted in the USA, but more recently studies have been conducted in Europe and other parts of the world. Some studies have explored the age-specific associations between daily variations in air pollution and mortality, especially in the elderly population that is assumed to be more vulnerable to air pollution effects than the general population [16]. Higher risks of particulate matter for deaths >65 yrs have been reported before in Philadelphia [17], Cincinnati [18], Amsterdam [1], Mexico City [19], Montreal [20] and Sao Paulo [21]. In a study in Rotterdam [2] TSP and especially O_3 RRs were substantially larger for deaths >78 yrs, the median age of death. In a study in six American cities, RR of PM2.5 (particles with a 50% cut-off aerodynamic diameter of 2.5 μm) exposure for subjects >65 yrs was only slightly higher than for the total population [22]. SUNYER *et al.* [23] in Barcelona and PRESCOTT *et al.* [24] in Edinburgh, found generally the same effect sizes in mortality effects of air pollution between older and younger age groups.

Thus, it seems from the existing literature that overall the elderly population seem to be at a slightly higher mortality risk for air pollution. Furthermore, it remains unclear whether elderly people are more sensitive to specific components in the air pollution mixture, although some of the studies suggest that particulate air pollution is most consistently associated with higher RR in the elderly.

Aim

Since information on age-specific and pollutant-specific RR is scarce and not yet clarified, the present authors evaluated the association between daily air pollution and daily mortality in the Netherlands for the period 1986–1994 [2] and, as a part of the study investigated whether the magnitude of the effect of air pollution depended on the age at death. Detailed information on the general study is given in HOEK *et al.* [6]. In this paper the age-specific analyses are described.

The aims of the analyses were: 1) to quantitate the age-specific associations between daily excess mortality and exposure to particulate matter, SO_2, CO, O_3, and NO_2 for the Dutch population, based on observed data from 1986–1994; and 2) to test differences in the age-specific associations between specific causes of death (cause specific mortality data), and between pollutants.

Methods

Mortality data for the whole of the Netherlands were obtained from the Central Bureau of Statistics (CBS) for the period 1986–1994. In January 1989 the total Dutch population counted 14.8 million people. Individuals who died due to external causes and infants <1-month old were excluded. For the analyses, total mortality, death counts from pneumonia (International Classification of Diseases (ICD)-9 480–486), chronic obstructive lung disease (ICD-9 490-496) and cardiovascular diseases (ICD-9 390–448) were selected.

Daily air quality data were obtained from 16 sites of the National Ambient Air Quality Monitoring Network (RIVM). Only population-oriented monitoring sites were selected where PM10 and/or BS was measured. In addition to daily mean data on PM10 and BS, daily mean data on the gaseous pollutants NO_2, SO_2, CO, and 8 h mean data on O_3 were used.

Hourly data on temperature and relative humidity were obtained from the national network of the Royal Dutch Meteorological Institute. Data on weekly incidence of influenza-type illnesses were obtained from the Dutch Institute of Primary Health Care.

Data analyses

The relationship between daily mortality and air pollution was modelled using Poisson regression analysis. All pollution/mortality associations were adjusted for potential confounding due to long-term trends, seasonal trends, influenza epidemics, ambient temperature, ambient relative humidity, day of the week and holidays, using generalised additive models with locally weighted regression (LOESS) smoothing as described before [2, 6]. The single-day air pollution concentrations with lags 1 day for O_3 and the weekly average concentration for other pollutants (average of lags 0–6 days) were used in the statistical analyses. These were the lags that correlated best in

Table 1. – Median (50th percentile) total, cardiovascular (CVD), chronic obstructive pulmonary diseases (COPD) and pneumonia daily mortality in the Netherlands (1986–1994) per age class (counts·day^{-1})

Age	Total	CVD	COPD	Pneumonia
<45	12	2	0	0
45–64	50	17	1	0
65–74	74	31	4	1
⩾75	192	90	10	8

the all age analyses. Final models were checked using the partial autocorrelation function of the residuals and plots of the residuals of the model *versus* date, temperature, influenza and relative humidity. Sensitivity analyses were conducted by examination of the impact of excluding days with very high concentrations; using less or more days for the smoothed date variable used for adjusting for seasonal trends; excluding days with the highest influenza counts; excluding the lowest and highest daily average temperatures; excluding relative humidity from the model. Age-specific analyses were performed for the age classes <45, 45–64, 65–74 and ⩾75 yrs. For presentation RRs were calculated for rounded differences between the 1st and 99th percentile of the air pollution variable. The ranges used were 80 for PM10; 40 for BS and SO_2; 30 for NO_2; 150 for O_3 and 1,200 for CO, all in µg·m^{-3}.

Results

On average, per day ~330 persons died in the Netherlands. In table 1 the median daily mortality per age class is presented. As can be seen from the table daily death counts due to COPD and pneumonia were small, especially in the younger age classes.

The distribution of the daily air pollution concentrations, weather and influenza counts is presented in table 2. Air pollution levels during the study period were comparable with levels found elsewhere in Western Europe. The correlations between PM10, BS, SO_2, NO_2 and CO were relatively high (0.6–0.9) indicating that it is difficult to separate the independent effects of these pollutants. Ozone had a small negative correlation with all other pollutants.

In figure 1 and table 3 the results of the mortality-air pollution analysis are presented. Statistically significant associations were mostly found in the elderly, that is the age categories of 65–74 and ⩾75 yrs for the pollutants PM10, BS, SO_2, NO_2 and CO. This is probably at least partly a reflection of the better precision of RR estimates due to the larger numbers of deaths in these age groups. Statistically significant associations for the age categories <65 yrs were found for O_3 (total and COPD mortality), PM10 (pneumonia), NO_2 (pneumonia) and CO (pneumonia).

Table 2. – Distribution (median, minimum, maximum) of the daily air pollution concentrations, weather and influenza counts in the Netherlands in the period 1986–1994

	Median	Min	Max
Air pollution concentrations µg·m^{-3}			
PM10	34	10	278
BS	10	1	120
O_3	47	1	226
NO_2	32	8	106
SO_2	10	1	247
CO	406	174	2620
Temperature °C	10	-13	26
Relative humidity %	84	44	100
Influenza counts·week^{-1} per 10,000 inhabitants	4	0	71

PM10: particles with a 50% cut-off aerodynamic diameter of 10 µM; BS: black smoke; O_3: ozone; NO_2: nitrogen dioxide; SO_2: sulphur dioxide; CO: carbon monoxide.

RR estimates for deaths between 45–65 yrs tended to be smaller than RRs for deaths >65 yrs, with the exception of O_3.

For cardiovascular mortality the RR for PM10, O_3 and CO of the latter age group were similar to the RR for deaths >65 yrs. Particulate matter air pollution (PM10 and BS) was not more consistently associated with mortality than were the gaseous pollutants.

Table 3 shows that larger RRs for air pollution were mostly found in the elderly group, with some exceptions for O_3 and pneumonia respectively.

Discussion

In the Netherlands short-term fluctuations of daily mortality were associated with short-term fluctuations in concentrations of all pollutants, both particulate and gaseous. For PM10, an overall RR of 1.02 for 100 µg·m^{-3} PM10 (95% CI 1.00–1.03) was found, which is comparable with recent estimates from the USA and the APHEA project. Age-specific analyses showed

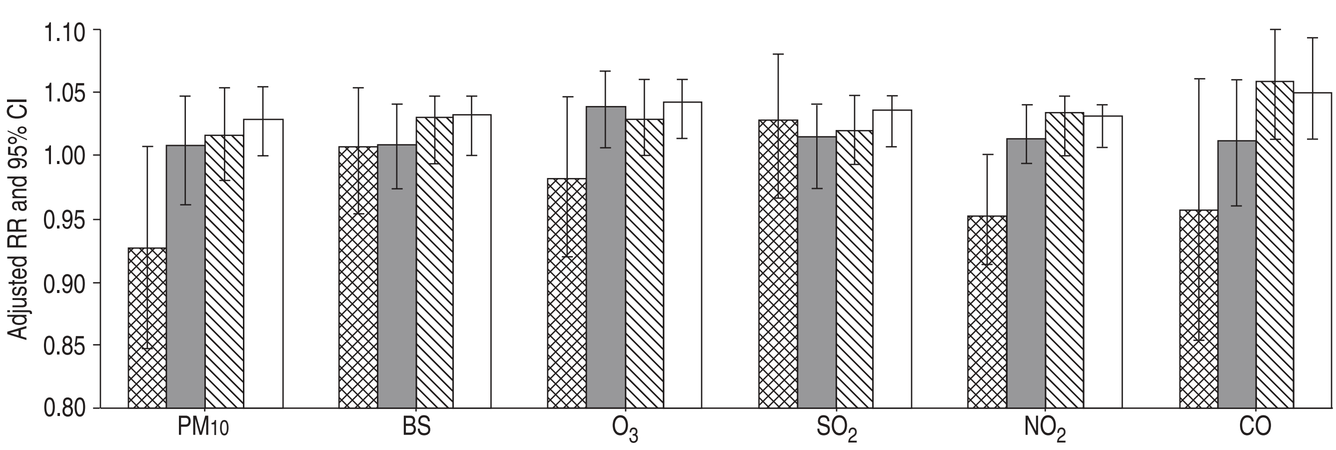

Fig. 1. – Association between air pollution and total mortality. Age classes: ■: <45 yrs; ■: 45–64 yrs; ▧: 65–74 yrs; □: ⩾75 yrs.

Table 3. – Association between air pollution and specific diseases

Pollutant	Age class	Cardiovascular	COPD	Pneumonia
PM_{10}	<45	0.906 (0.728–1.128)	1.153 (0.587–2.268)	1.427 (0.806–2.525)
	45–64	1.023 (0.945–1.106)	1.139 (0.841–1.541)	1.712 (1.042–2.815)
	65–74	1.002 (0.945–1.062)	1.166 (0.991–1.372)	1.240 (0.879–1.748)
	⩾75	1.016 (0.981–1.052)	1.066 (0.965–1.178)	1.123 (1.011–1.247)
BS	<45	1.057 (0.934–1.196)	0.872 (0.599–1.270)	0.741 (0.519–1.057)
	45–64	1.000 (0.957–1.046)	1.025 (0.870–1.209)	1.264 (0.934–1.711)
	65–74	1.040 (1.006–1.075)	1.204 (1.095–1.324)	0.951 (0.767–1.179)
	⩾75	1.030 (1.010–1.051)	1.012 (0.957–1.070)	1.123 (1.055–1.196)
O_3	<45	1.022 (0.863–1.212)	2.137 (1.258–3.630)	1.142 (0.682–1.911)
	45–64	1.038 (0.977–1.103)	1.083 (0.856–1.371)	0.677 (0.424–1.081)
	65–74	1.005 (0.960–1.053)	0.989 (0.862–1.135)	1.597 (1.164–2.190)
	⩾75	1.073 (1.044–1.102)	0.996 (0.919–1.079)	1.367 (1.245–1.501)
SO_2	<45	1.060 (0.937–1.200)	0.737 (0.490–1.108)	0.708 (0.482–1.038)
	45–64	0.993 (0.949–1.038)	0.915 (0.771–1.087)	0.946 (0.682–1.311)
	65–74	1.023 (0.989–1.059)	1.137 (1.032–1.251)	0.860 (0.678–1.089)
	⩾75	1.039 (1.018–1.060)	1.026 (0.967–1.089)	1.099 (1.028–1.175)
NO_2	<45	0.990 (0.897–1.094)	0.818 (0.610–1.097)	0.865 (0.650–1.151)
	45–64	0.997 (0.962–1.033)	1.053 (0.920–1.205)	1.406 (1.092–1.810)
	65–74	1.034 (1.007–1.063)	1.173 (1.085–1.268)	1.067 (0.897–1.269)
	⩾75	1.027 (1.011–1.044)	1.046 (1.000–1.094)	1.129 (1.072–1.188)
CO	<45	0.965 (0.750–1.240)	1.710 (0.852–3.435)	0.927 (0.463–1.856)
	45–64	1.029 (0.941–1.125)	1.181 (0.850–1.640)	2.691 (1.509–4.800)
	65–74	1.038 (0.972–1.108)	1.377 (1.147–1.654)	1.118 (0.743–1.683)
	⩾75	1.024 (0.984–1.065)	1.072 (0.963–1.193)	1.230 (1.090–1.389)

Data are presented as adjusted relative risk (95% confidence intervals). COPD: chronic obstructive pulmonary disease; PM_{10}: particles with a 50% cut-off aerodynamic diameter of 10 μM; BS: black smoke; O_3: ozone; NO_2: nitrogen dioxide; SO_2: sulphur dioxide; CO: carbon monoxide.

that statistically significant associations between air pollution and mortality were mostly found in the elderly (>65 yrs) and that the RR for deaths <65 yrs were generally smaller than in the older age classes. Exceptions were the associations between O_3 and COPD in the younger ages and between air pollution and pneumonia deaths which showed high RR in the age group 45–64 yrs, suggesting that for some death causes (pneumonia) younger age groups seem to be at risk too. Both particulate matter and gaseous components were associated with statistically significant mortality effects in the elderly age groups indicating no preference for a specific air pollutant in the mortality associations.

Higher RRs of particulate matter for deaths in the >64-yr age group have been found in Philadelphia (RR for 100 $\mu g \cdot m^{-3}$ TSP: 1.10 (95% CI 1.06–1.13) in the ⩾65 yr age group *versus* 1.03 (1.03–1.10) in the <65 yr age group) [17], Cincinnati (RR for 100 $\mu g \cdot m^{-3}$ TSP: 1.09 (95% CI 1.05–1.14) in the >64 yr age group *versus* 1.06 (1.03–1.10) in all ages) [18] and Amsterdam (RR for 100 $\mu g \cdot m^{-3}$ BS: 1.26 (95% CI 1.07–1.49) in the >64 yr age group *versus* 1.19 (1.02–1.38) in all ages; and RR for 100 $\mu g \cdot m^{-3}$ PM_{10}: 1.07 (95% CI 0.98–1.16) in the >64 yr age group *versus* 1.06 (0.99–1.14) in all ages) [1], and more recently in Montreal (RR for 12.5 $\mu g \cdot m^{-3}$ $PM_{2.5}$: 1.03 (95% CI 1.02–1.04) in the ⩾64 yr age group *versus* 1.01 (0.99–1.03) in <65 yr age group) [20]. For Rotterdam, TSP and especially O_3 RRs were substantially larger for deaths <78 yrs, the median age at death (RR for 91 $\mu g \cdot m^{-3}$ TSP: 1.06 (95% CI 1.01–1.11) in the >78 yr age group *versus* 1.04 (0.99–1.10) in the <78 yr age group; RR for 67 $\mu g \cdot m^{-3}$ O_3: 1.13 (95% CI 1.06–1.20) in the >78 yr age group *versus* 1.0 in the <78 yr age group [2]. In six cities in the USA [22] an increase in daily total mortality of 1.5% per 10 $\mu g \cdot m^{-3}$ $PM_{2.5}$ was found in the total population and a slightly increased mortality of 1.7% in the elderly (⩾65 yrs).

PRESCOTT *et al.* [24] found generally equal effect sizes in mortality effects of air pollution between the two age groups (<65 yrs, ⩾65 yrs), but in the people aged ⩾65 yrs, daily all-cause mortality and respiratory mortality had statistically significant association with BS. For other air pollution components (SO_2, PM_{10}, NO_2, O_3 and CO) no significant associations were found with all cause, cardiovascular or respiratory causes mortality. BORJA-Aburto *et al.* [19] also found somewhat larger excesses of death among people >65 yrs in Mexico City in association with $PM_{2.5}$ levels, but for other components (O_3, NO_2) this was not the case. GOUVEIA and FLETCHER [21] in Sao Paulo, Brazil, showed that older age groups seemed to be at higher risks of mortality associated with air pollution. While total causes mortality was significantly associated with air pollution in the age group >65 yrs, no significant effects of air pollution were observed for <65-yr age groups, although for most of the air pollution components that were analysed, an RR above unity was observed. An increase in total mortality of 5% and 17% for a 100 $\mu g \cdot m^{-3}$ increase in PM_{10} and SO_2 respectively was found in the elderly group compared to 1% and 5% in the younger age group. GOLDBERG *et al.* [20] in a study in Montreal, Quebec, also found higher excesses in daily mortality for persons 65-yrs-old for daily variations in several measures of particulate air pollution. In general the estimated mean percentage change in daily nonaccidental mortality for an increase in levels of pollution across the interquartile range differed between 1–2% depending on the exposure measure selected [20].

In the current study associations were not only found for particulate air pollutants, but also for gaseous air pollutants. This is partly caused by the high co-linearity between the pollutants. However, in two pollutant models (not presented) RR estimates for gases remained significant [2, 6], suggesting that factors other than particle indicators for the air pollution mixture are important as well. For a 100 $\mu g \cdot m^{-3}$ increase in PM_{10} there was a nonsignificant increase in total mortality of 1% for the younger age categories (<65 yrs) compared to a significant increase in daily mortality of 2–3% in the elderly (⩾65 yrs). This is in the order of the effect sizes found by GOUVEIA and FLETCHER [21] and GOLDBERG and coworkers

[20, 25], and in agreement with other studies. The present authors' results from the analyses of the gaseous components showed statistically significant associations with total and cause-specific mortality indicating that other factors than particulate matter that are causally associated with mortality cannot be excluded. The current authors do not interpret the associations found for the gaseous pollutants SO_2 and NO_2 at the concentration levels in the Netherlands as causal [26].

To conclude, overall, the elderly (>65 yrs) are at higher risk for acute mortality effects of air pollution compared to younger age groups.

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