

2003

Short-Term Effects of Ambient Particles on Mortality in the Elderly: Results from 28 Cities in the APHEA2 Project


E. Aga
University of Athens

E. Samoli
University of Athens

G. Touloumi
University of Athens

See next page for additional authors

Follow this and additional works at: <https://arrow.tudublin.ie/scschphyart>

 Part of the [Medicine and Health Sciences Commons](#), and the [Physical Sciences and Mathematics Commons](#)

Recommended Citation

Katsouyanni, K. et al. (2003) Short-Term Effects of Ambient Particles on Mortality in the Elderly: Results from 28 Cities in the APHEA2 Project, *European Respiratory Journal*, 2003; 21: Suppl. 40, 28s–33s.
doi:10.1183/09031936.03.00402803

This Article is brought to you for free and open access by the School of Physics & Clinical & Optometric Science at ARROW@TU Dublin. It has been accepted for inclusion in Articles by an authorized administrator of ARROW@TU Dublin. For more information, please contact arrow.admin@tudublin.ie, aisling.coyne@tudublin.ie.



This work is licensed under a [Creative Commons Attribution-NonCommercial-Share Alike 4.0 License](#)

Authors

E. Aga, E. Samoli, G. Touloumi, K. Katsouyanni, H.R. Anderson, E. Cadum, B. Forsberg, Patrick J. Goodman, A. Goren, F. Kotesovec, B. Kriz, M. Macarol-Hiti, S. Medina, A. Paldy, C. Schindler, J. Sunyer, P. Tittanen, B. Wojtyniak, D. Zmirou, and J. Schwartz

Short-term effects of ambient particles on mortality in the elderly: results from 28 cities in the APHEA2 project

E. Aga*, E. Samoli*, G. Touloumi*, H.R. Anderson[#], E. Cadum[¶], B. Forsberg⁺, P. Goodman[§], A. Goren^f, F. Kotesovec^{**}, B. Kriz^{###}, M. Macarol-Hiti^{¶¶}, S. Medina⁺⁺, A. Paldy^{§§}, C. Schindler^{ff}, J. Sunyer^{***}, P. Tittanen^{###}, B. Wojtyniak^{¶¶¶}, D. Zmirou⁺⁺⁺, J. Schwartz^{§§§}, K. Katsouyanni*

Short-term effects of ambient particles on mortality in the elderly: results from 28 cities in the APHEA2 project. E. Aga, E. Samoli, G. Touloumi, H.R. Anderson, E. Cadum, B. Forsberg, P. Goodman, A. Goren, F. Kotesovec, B. Kriz, M. Macarol-Hiti, S. Medina, A. Paldy, C. Schindler, J. Sunyer, P. Tittanen, B. Wojtyniak, D. Zmirou, J. Schwartz, K. Katsouyanni. ©ERS Journals Ltd 2003.

ABSTRACT: Within the framework of the APHEA2 (Air Pollution on Health: a European Approach) project, the effects of ambient particles on mortality among persons ≥ 65 yrs were investigated.

Daily measurements for particles with a 50% cut-off aerodynamic diameter of 10 μm (PM₁₀) and black smoke (BS), as well as the daily number of deaths among persons ≥ 65 yrs of age, from 29 European cities, have been collected. Data on other pollutants and meteorological variables, to adjust for confounding effects and data on city characteristics, to investigate potential effect modification, were also recorded. For individual city analysis, generalised additive models extending Poisson regression, using a locally weighted regression (LOESS) smoother to control for seasonal effects, were applied. To combine individual city results and explore effect modification, second stage regression models were applied.

The per cent increase (95% confidence intervals), associated with a 10 $\mu\text{g}\cdot\text{m}^{-3}$ increase in PM₁₀, in the elderly daily number of deaths was 0.8% (0.7–0.9%) and the corresponding number for BS was 0.6% (0.5–0.8%). The effect size was modified by the long-term average levels of nitrogen dioxide (higher levels were associated with larger effects), temperature (larger effects were observed in warmer countries), and by the proportion of the elderly in each city (a larger proportion was associated with higher effects).

These results indicate that ambient particles have effects on mortality among the elderly, with relative risks comparable or slightly higher than those observed for total mortality and similar effect modification patterns. The effects among the older persons are of particular importance, since the attributable number of events will be much larger, compared to the number of deaths among the younger population.

Eur Respir J 2003; 21: Suppl. 40, 28s–33s.

The APHEA (Air Pollution on Health: a European Approach) project [1–3] started as an attempt to provide quantitative estimates of the short-term health effects of air pollution, using an extensive database from 10 different European countries (15 cities with >25 million people), through time series data and meta-analysis.

Daily measurements of black smoke (BS), sulphur dioxide (SO₂), suspended particles (as total or particles with an aerodynamic diameter smaller than a certain cut off), nitrogen dioxide (NO₂) and ozone (O₃) were derived from existing monitoring networks. The outcome data were daily counts of total and cause-specific deaths and hospital emergency admissions. Data on potential confounders (*e.g.* seasonal and long term patterns, meteorological factors, day of the week, holidays, influenza epidemics, unusual events such as strikes of medical staff) were also used.

Poisson regression allowing for autocorrelation and over-dispersion was used in the analysis, controlling for all potential confounding factors, choosing the "best" air pollution models, and applying diagnostic tools to check the adequacy of the models.

The results of APHEA were firstly reported in a series of articles describing the individual contributions to the collaborative effort: Bratislava, Slovak Republic [4]; Amsterdam and Rotterdam, the Netherlands [5]; Lyon, France [6]; Cracow, Lodz, Poznan, and Wroclaw, Poland [7]; Paris, France [8]; Athens, Greece [9]; Koln, Germany [10]; Helsinki, Finland [11]; Milan, Italy [12].

Subsequently, the APHEA results were reported in a series of articles describing the pooled findings of the health outcomes for a 50 $\mu\text{g}\cdot\text{m}^{-3}$ increase in daily mean level of a single pollutant.

ANDERSON *et al.* [13] found increased probabilities of hospital admissions for chronic obstructive pulmonary disease (COPD) ranging 2–4%; KATSOUYANNI *et al.* [14], investigated particles and SO₂, and found increases in daily mortality ranging 2–3% in Western European cities and from 0.6–0.8% in Central Eastern European cities (with stronger effects during the summer); TOULOUMI *et al.* [15], who investigated NO₂ and O₃, found a 1.3–2.9% increase of daily number of deaths, respectively; SUNYER *et al.* [16] described daily admissions for asthma that increased as follows: significantly by

*Dept Hygiene-Epidemiology, University of Athens, Athens, Greece, [#]St. George's Hospital Medical School, London, UK, [¶]Environmental Protection Agency of Piemonte, Torino, Italy, ⁺Umeå University, Umeå, Sweden, [§]Dublin Institute of Technology, Dublin, Ireland, ^{¶¶}Tel-Aviv University, Tel-Aviv, Israel, ^{**}Institute of Hygiene, Teplice, Czech Republic, ^{###}Charles University, Prague, Czech Republic, ^{¶¶¶}Institute of Public Health, Ljubljana, Slovenia, ⁺⁺Institut de Veille Sanitaire, Saint Maurice, France, ^{§§}National Public Health Center, Budapest, Hungary, ^{ff}University of Basel, Basel, Switzerland, ^{***}Institute Municipal d'Investigacio Medica (IMIM), Barcelona, Spain, ^{####}National Public Health Institute, Kuopio, Finland, ^{¶¶¶¶}National Institute of Hygiene, Warsaw, Poland, ⁺⁺⁺INSERM U420, Nancy, France, ^{§§§}Harvard School of Public Health, Boston, USA.

Correspondence: K. Katsouyanni, Dept of Hygiene and Epidemiology, University of Athens Medical School, 75 Mikras Asias street, 115 27 Athens, Greece.
Fax: 30 2107462080
E-mail: kksatouy@med.uoa.gr

Keywords: Ambient particles, elderly, mortality, nitrogen dioxide, time series

Received and accepted: April 12 2002

2.9% with increasing ambient levels of NO₂, nonsignificantly by 2.1% with BS in adults (15–64 yr); significantly by 7.5% with SO₂ and by 8% in cold seasons with NO₂, and nonsignificantly by 3% with BS in children <15 yrs.

SPIX *et al.* [17], from the quantitative pooling of local analyses on five West European cities, found a significant increase of daily admissions for respiratory diseases (adults of 15–64 yrs and elderly of ≥65 yrs) with elevated levels of O₃. This finding was stronger in the elderly, had a rather immediate effect, and was homogeneous over cities. The elderly were affected more during the warm season. The effect of BS was significantly stronger with high NO₂ levels on the same day. O₃ results were in good agreement with the results of similar USA studies.

ZMIROU *et al.* [18], from a meta-analysis on 10 large European cities, found that daily deaths from cardiovascular conditions increased 2% with BS, 2% with O₃ and 4% with SO₂; the analogous figures for respiratory diseases were 4, 6 and 5%, respectively. This occurred in Western but not in Central European cities.

Some papers [19–21] summarised and commented on the APHEA findings and considered the theoretical and practical aspects of a monitoring system and made recommendations concerning the minimum data-set required, the methods of statistical analysis and presentation, and Europe-wide coordination of monitoring.

One intriguing finding was that the effects were lower in Central-Eastern European cities. SAMOLI *et al.* [22] reanalysed through generalised additive models the original data by restricting to days with pollutant concentration <150 µg·m⁻³. The new estimates for increase in mortality, only in Central-Eastern European cities, were larger than the ones published previously: by 69% for BS and 55% for SO₂. Thus, part of the heterogeneity in the estimates of air pollution effects had been caused by the statistical approach and lack of threshold for pollutant levels.

Overall, through the APHEA study, the existence of an association between daily variations in the levels of urban air pollution and adverse health effects was confirmed in Europe. This association is weak, but it involves the whole resident population, so it is a major cause of concern from the public health point of view.

APHEA methodology has been discussed and utilised by other investigators, as well [23–33].

The APHEA (Air Pollution on Health: a European Approach) project

During the last decade consistent results from several epidemiological studies have indicated that current concentrations of ambient particulate matter (PM) have adverse health effects including increases in daily mortality [34, 14]. Important evidence was added to these results by multicentre studies such as the APHEA project in Europe [1–22] and the National Mortality Morbidity and Air Pollution Study (NMMAPS) in the USA [35], which included data from several cities collected and analysed using a standardised protocol. The above results influenced the revisions of air quality standards in the USA and in Europe [36, 37].

Recently, attention has shifted to understanding, among other issues, which particular population groups are more sensitive to these effects [38]. The elderly, which are proportionally increasing in Europe, are a group of special interest.

The APHEA2 project was implemented, as a continuation of the APHEA project, based on a more extended database, with objectives to address the consistency of associations, to identify sensitive subpopulations and specific particle

characteristics, and to explore confounding and effect modification [39, 40].

The estimated increase in the daily number of deaths for all ages for a 10 µg·m⁻³ increase in daily particles with a 50% cut-off aerodynamic diameter of 10 µm (PM10) or BS concentrations was 0.6%, whereas for the elderly it was slightly higher [39]. There were important effect modifications for several variables: *e.g.* in a city with low *versus* one with high average NO₂, the estimated increase was 0.19 *versus* 0.80%; in a relatively cold *versus* one with warm climate 0.29 *versus* 0.82%; in a city with low *versus* one with high standardised mortality rate 0.80 *versus* 0.43%. For the same pollutants increase, ATKINSON *et al.* [40] found increase in daily hospital admission for: asthma (0–14 yrs) of 1.2%, asthma (15–64 yrs) of 1.1%, and COPD plus asthma and all-respiratory (≥65 yrs) of 1.0 and 0.9%. In the ≥65 groups PM10 estimates were positively associated with annual mean concentrations of O₃. ZANOBETTI *et al.* [41] analysed the mortality displacement issue, *i.e.* if it is due solely to the deaths of frail individuals, which are brought forward by only a brief period of time. They fit a Poisson regression model and a polynomial distributed lag model with up to 40 days of delay in each city. They found that the overall effect of PM10 per 10 µg·m⁻³ for the fourth-degree distributed lag model is a 1.61% increase in daily deaths (95% confidence interval (CI): 1.02–2.20), whereas the mean of PM10 on the same day and the previous day is associated with only a 0.70% increase in deaths (95% CI: 0.43–0.97). Thus, the effect size estimate for airborne particles more than doubles when longer-term effects are considered, which has important implications for risk assessment.

This paper reports the results of the APHEA2 project on the effects of daily PM on mortality among persons ≥65 yrs, in 28 European cities.

Data and methods

Data was collected from 28 cities across Europe: Athens, Barcelona, Basel, Bilbao, Birmingham, Budapest, Cracow, Dublin, Geneva, Helsinki, Ljubljana, Lodz, London, Lyon, Madrid, Marseille, Milano, Paris, Poznan, Prague, Rome, Stockholm, Tel-Aviv, Teplice, Torino, Valencia, Wroclaw, Zurich with a total population exceeding 43 million. The study period was ~5 yrs for most cities, within the nineties. The health outcome in the present analysis was the daily number of deaths (excluding deaths from external causes, International Classification of Diseases (ICD)9 ≥800) among persons ≥65-yrs-old, which ranged, in the different cities, from 4–139 on average per day. PM10 concentrations were contributed for the whole or part of the period (or could be estimated based on other studies) from 21 cities: the 24 hr concentrations ranged from 15 µg·m⁻³ to 66 µg·m⁻³ on average. Fourteen cities contributed daily BS measurements; these ranged 10–64 µg·m⁻³ (24 h concentrations). Measurements of air pollutants were provided by monitoring networks established in each town. The selection criteria for monitors to be included in the study (based on completeness of measurements) and the methods for replacing the few remaining missing values are described elsewhere [39]. Data was also collected on potential confounders: other pollutants (specifically SO₂, NO₂, O₃, carbon monoxide), meteorological variables (daily temperature and relative humidity), influenza epidemics. Day of the week, national and school holidays, seasonality and long-term trends were also adjusted for. Since significant heterogeneity between individual city estimates had been observed before [14], the present authors collected information on potential effect modifiers characterising the

city with respect to the pollutant mix, the status of health of the population, climate and geography [39].

A two-stage analysis was applied. In the first stage, city-specific regression models were fitted and their results were used in a second stage analysis to provide overall estimates and to investigate effect modification. Days with PM₁₀ or BS levels >150 µg·m⁻³ were excluded. These days did not exceed 5% of the total number of days. Generalised additive models, extending Poisson regression were applied allowing for overdispersion. Local nonparametric locally weighted regression (LOESS) smoothers were used to control for seasonal patterns and long-term trends. Temperature, humidity, day of the week, holidays, unusual events and influenza epidemics were also appropriately controlled for [39]. For PM₁₀ and BS, the average concentrations of lags 0 and 1 was *a priori* chosen as exposure measure. For the second stage analysis, *i.e.* the combination of results across cities, meta-regression models were used. These allowed the estimation of combined effects and the investigation of the role of potential effect modifiers in explaining observed heterogeneity. Fixed and random effects models were used as appropriate. More details on the data and methods have been reported elsewhere [39].

Results

In figure 1 the individual city as well as the pooled effect estimates for the daily number of deaths among the elderly, associated with a PM₁₀ increase of 10 µg·m⁻³ are shown. The individual city effect estimates are positive for all cities except one. They range from an increase in the daily number of deaths of 0–1.7%, associated with 10 µg·m⁻³ increase in daily PM₁₀ concentrations. In figure 2 the corresponding effect estimates for a similar increase in BS are shown. BS effects in individual cities range from 0–1.6% increase in the daily number of deaths associated with a daily increase of 10 µg·m⁻³ in BS concentrations. In table 1 the pooled estimated effect from fixed and random effects models for the elderly and those for all ages (for comparison) are shown. It should be noted that

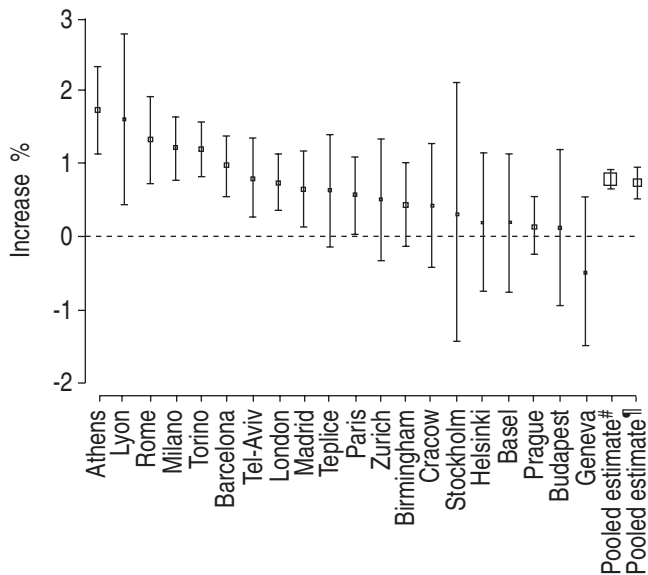


Fig. 1.—Estimated per cent increase and 95% confidence intervals in the daily number of deaths of persons ≥ 65 -yrs-old associated with an increase of 10 µg·m⁻³ in the levels of particles with a 50% cut-off aerodynamic diameter of 10 µm (PM₁₀) for individual cities and overall. The size of the data point is inversely proportional to its variance. #: fixed effect; †: random effect.

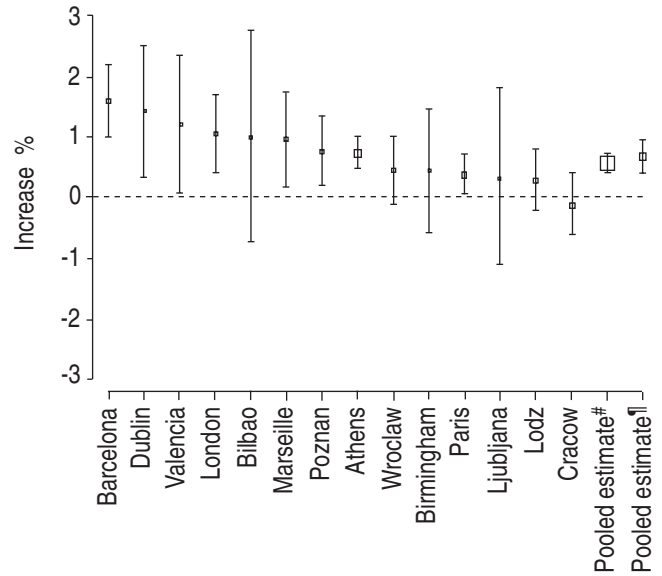


Fig. 2.—Estimated per cent increase and 95% confidence intervals in the daily number of deaths of persons ≥ 65 -yrs-old associated with an increase of 10 µg·m⁻³ in the levels of black smoke for individual cities and overall. The size of the data point is inversely proportional to its variance. #: fixed effect; †: random effect.

published estimates for all ages mortality included one more city, Erfurt in Germany, in which the daily number of deaths for the elderly was not available [39]. For reasons of comparability, the present authors calculated here the combined estimates without Erfurt. The pooled effects remain practically the same since Erfurt had little weight in the combined analysis, due to its small population. The effect estimates for the elderly are consistently higher compared to those for all ages. In tables 2 and 3 the results on effect modification are shown for PM₁₀ and BS estimates respectively. Only effect modifiers which are statistically significant ($p < 0.05$) and explain >10% of the heterogeneity are presented. To illustrate the magnitude of the effect modification, the effect estimated for a city with "low" level in the effect modifier (*i.e.* at the 25th percentile of the corresponding effect modifying variable distribution) and that estimated for a city with "high" level in the effect modifier (*i.e.* at the 75th percentile of its distribution) are presented. Thus, it can be seen that, for the most important effect modifier identified, long term NO₂ concentration, the effect of PM₁₀ on the daily number of deaths among the elderly, ranges from 0.30% in cities with low long-term average NO₂ (about 40 µg·m⁻³) to 0.97% in cities with high long-term average NO₂ (about 70 µg·m⁻³).

Table 1.—Pooled estimates for the increase in the total daily number of deaths and deaths among the elderly associated with a 10 µg·m⁻³ increase in particles with a 50% cut-off aerodynamic diameter of 10 µm (PM₁₀) and black smoke (BS) (average concentrations of lags 0 and 1)

Mortality	PM ₁₀	BS
Among ≥ 65 -yr-olds		
Fixed effects model	0.79 (0.66–0.92)	0.63 (0.49–0.78)
Random effects model	0.74 (0.52–0.95)	0.68 (0.43–0.92)
Total		
Fixed effects model	0.71 (0.60–0.83)	0.51 (0.39–0.64)
Random effects model	0.67 (0.47–0.87)	0.58 (0.32–0.84)

Data are presented as per cent increase (95% confidence interval).

Table 2. – Results of the second stage regression models investigating the role of potential effect modifiers[#] of the estimated effects of particles with a 50% cut-off aerodynamic diameter of 10 μm (PM₁₀) on the daily number of natural deaths among persons ≥ 65 yrs old

Effect modifier in model [†]	Mean over the study period 25th, 75th percentiles	Increase in the daily number of deaths associated with an increase of 10 $\mu\text{g}\cdot\text{m}^{-3}$ in PM ₁₀ concentrations, at levels of effect modifier equal to:	
		25th percentile	75th percentile
24 h NO ₂ $\mu\text{g}\cdot\text{m}^{-3}$	40, 70	0.30 (0.07–0.53)	0.97 (0.82–1.11)
24 h temperature °C	9, 15	0.44 (0.25–0.64)	0.91 (0.77–1.05)
24 h relative humidity %	66, 77	0.98 (0.82–1.14)	0.52 (0.33–0.71)
Age standardised annual mortality rate per 100,000	666, 972	0.93 (0.77–1.09)	0.61 (0.43–0.79)
Proportion of individuals ≥ 65 yrs %	13, 17	0.67 (0.50–0.83)	0.85 (0.71–0.99)
Geographical region			
Northwest/Central-East		0.81 (0.63–0.98)	0.26 (-0.05–0.57)
Northwest/South		0.81 (0.63–0.98)	1.04 (0.81–1.27)

Data are presented as estimated per cent increase (95% confidence interval) unless otherwise stated. [#]These are variables characterising each city. Only effect modifiers reducing the heterogeneity by >10% are presented; [†]The effect modifiers were included alternatively in the model. NO₂: nitrogen dioxide.

Table 3. – Results of the second stage regression models investigating the role of potential effect modifiers[#] of the estimated effects of black smoke (BS) on the daily number of natural deaths among persons ≥ 65 yrs old

Effect modifier in model [†]	Mean over the study period 25th, 75th percentiles	Increase in the daily number of deaths associated with an increase of 10 $\mu\text{g}\cdot\text{m}^{-3}$ in BS concentrations, at levels of effect modifier equal to:	
		25th percentile	75th percentile
24 h NO ₂ $\mu\text{g}\cdot\text{m}^{-3}$	40, 70	0.44 (0.26–0.62)	0.74 (0.58–0.90)
24 h temperature °C	9, 15	0.39 (0.18–0.60)	0.75 (0.59–0.91)
24 h relative humidity %	66, 77	0.65 (0.51–0.80)	0.49 (0.28–0.69)
Proportion of individuals ≥ 65 yrs %	13, 17	0.59 (0.45–0.73)	0.85 (0.65–1.05)
Geographical region			
Northwest/Central-East		0.58 (0.30–0.85)	0.31 (0.05–0.58)
Northwest/South		0.58 (0.30–0.85)	0.87 (0.66–1.09)

Data are presented as estimated per cent increase (95% confidence interval) unless otherwise stated. [#]These are variables characterising each city. Only effect modifiers reducing the heterogeneity by >10% are presented; [†]The effect modifiers were included alternatively in the model. NO₂: nitrogen dioxide.

Other important effect modifying variables are the temperature and relative humidity levels (PM₁₀ effects are higher in warmer and drier cities), the age-standardised annual mortality rate (higher mortality is associated with lower PM₁₀ effects), the proportion of the elderly (a higher proportion of elderly is associated with higher PM₁₀ effects) and geographical region (effects are highest in Southern and lowest in the Central-Eastern cities). It should be noted that these effect modifying variables were included in the models alternatively and the effects reported may be partly due to their intercorrelations. The effect modification pattern for BS effects is similar to that for PM₁₀. When three effect modifiers were included in one model (the most important ones from each category, *i.e.* NO₂, temperature and age-standardised mortality rate or the proportion of the elderly) the *p*-value for the remaining heterogeneity was >0.20.

Discussion

The present study estimated the effect of daily ambient particulate matter concentrations on the number of deaths among the elderly (persons ≥ 65 -yrs-old) in 28 European cities, using the database compiled within the APHEA2

project [39]. The effect estimates were consistently larger, by 10–20%, than those estimated for all age mortality from an identical database. The effects of two different ambient particle measures, PM₁₀ and BS, were comparable.

In the studied cities elderly mortality comprised 67–88% of the total number of deaths, thus playing a predominant role in determining the magnitude of all age mortality. In other studies in which the effect of particles on mortality has been investigated, the age distribution of those who died on any given day was different. Thus, in a study in Sao Paulo, Brazil [42], the percentage of deaths among those >65 yrs was only 49%. In that study, the effect of a daily change of 10 $\mu\text{g}\cdot\text{m}^{-3}$ in PM₁₀ on the daily number of deaths from all causes among the elderly was found to be a 0.5% increase, which is comparable to the one reported from the present analysis, but slightly smaller. The difference in size may be due to the use of a one day PM measurement in the Brazilian study, whilst in APHEA2 the average of lags 0 and 1 was used. It has been shown that longer time averages result in higher estimates [43]. This difference may also be attributable to a higher mean age of death in the APHEA2 populations compared to Sao Paulo. If older age groups are consistently at higher risk of death from air pollution, then it will be expected that, in a population where the mean age is higher, larger PM effects

will be observed. In studies conducted in places where the age-distribution of the population is similar to that in Europe, the results were close to those reported here. Thus, in a study in Canada [44] the increase in mortality among the elderly associated with a $10 \mu\text{g}\cdot\text{m}^{-3}$ increase in PM₁₀ was found to be 0.69% for lag₀ and 0.79% for lag₁ whilst that for all ages was 0.67% for lag₀ and 0.36% for lag₁. In the USA NMMAPS [35] the increase in the daily number of deaths for all ages associated with a $10 \mu\text{g}\cdot\text{m}^{-3}$ change in PM₁₀ was 0.5%.

The city specific estimates in the current study were heterogeneous, as were those reported before for all age total and cause-specific mortality [14, 18, 39]. One objective of the APHEA2 project was to investigate the reasons for this heterogeneity. In this analysis important effect modifiers have been identified. They are generally consistent to those reported for the all age mortality [39]. Thus, higher long-term average NO₂ concentrations are associated with larger PM effects. Since NO₂ is mainly an indicator of pollution originating from traffic and it is likely that in locations with high NO₂ there will be more traffic-related particles, this result may be considered as an indication that these particles are more harmful to human health. Higher PM effects are found in warmer and drier climates. This finding may be due to a higher exposure to outdoor air pollution of populations living in milder climates and should be further investigated using additional data on time-activity patterns, housing and ventilation conditions. It is also found that in cities with higher age-standardised mortality rate, PM effects on the elderly are smaller, in relative terms. This may be a result of competing risks and the health status of the population and is consistent with the results published by GOUVEIA and FLETCHER [42]. It is expected that in populations with higher underlying mortality rate the proportional increase in the outcome due to air pollution exposure will be smaller [39, 42].

An interesting finding in the present context, is that the proportion of the elderly appears as modifying the PM effect on elderly mortality. This implies that the PM effect is not constant across different age subgroups among those ≥ 65 yrs. The average PM effect in an elderly population, thus, probably depends on the mean age of this population. It is plausible to expect that in cities with a larger proportion of elderly, the population group of those ≥ 65 will also have a higher mean age. In this case, if PM effects increase with age, then higher mean age would result in larger effect estimates. The present authors' result and that reported by GOUVEIA and FLETCHER [42] are in line with this hypothesis.

Acknowledgements. The APHEA2 project was supported by the EC Environment and Climate 1994-98 project, Contract number ENV4-CT97-0534. The Swedish and Teplice groups did not receive E.C. funding.

The Air Pollution and Health: a European Approach (APHEA2) collaborative group consists of: K. Katsouyanni, G. Touloumi, E. Samoli, A. Gryparis, Y. Monopoli, E. Aga, D. Panagiotakos (Greece, Coordinating centre); C. Spix, A. Zanobetti, H.E. Wichmann (Germany); HR Anderson, R. Atkinson, J. Ayres (UK); S. Medina, A. Le Tertre, P. Quenel, L. Pascale, A. Boumghar (Paris, France); J. Sunyer, M. Saez, F. Ballester, S. Perez-Hoyos, J.M. Tenias, E. Alonso, K. Kambra, E. Aranguiz, A. Gandarillas, I. Galan, J.M. Ordonez (Spain); M.A. Vigotti, G. Rossi, E. Cadum, G. Costa, L. Albano, D. Mirabelli, P. Natale, L. Bisanti, A. Bellini, M. Baccini, A. Biggeri, P. Michelozzi, V. Fano, A. Barca, F. Forastiere (Italy); D. Zmirou, F. Balducci (Grenoble, France); J. Schouten, J. Vonk (the Netherlands); J. Pekkanen, P. Tittanen (Finland); L. Clancy,

P. Goodman (Ireland); A. Goren, R. Braunstein (Israel); C. Schindler (Switzerland); B. Wojtyniak, D. Rabchenko, K. Szafraniec (Poland); B. Kriz, A.M. Celko, J. Danova (Prague, Czech Republic); A. Paldy, J. Bobvos, A. Vamos, G. Nador, I. Vincze, P. Rudnai, A. Pinter (Hungary); E. Niciu, V. Frunza, V. Bunda, (Romania); M. Macarol-Hitti, P. Otorepec (Slovenia); Z. Dörtbudak, F. Erkan (Turkey); B. Forsberg, B. Segerstedt, (Sweden); F. Kotesovec, J. Skorkovski (Teplice, Czech Republic); M. Pavlovic, D. Simic (Croatia).

References

1. Katsouyanni K, Zmirou D, Spix C, *et al.* Short-term effects of air pollution on health: a European approach using epidemiological time-series data. The APHEA project: background, objectives, design. *Eur Respir J* 1995; 8: 1030-1038.
2. Katsouyanni K, Schwartz J, Spix C, *et al.* Short term effects of air pollution on health: a European approach using epidemiologic time series data: the APHEA protocol. *J Epidemiol Community Health* 1996; 50: Suppl. 1, S12-S18.
3. Katsouyanni K, Zmirou D, Spix C, *et al.* Short-term effects of air pollution on health: a European approach using epidemiologic time series data. The APHEA Project. Air Pollution Health Effects - A European Approach. *Public Health Rev* 1997; 25: 7-18.
4. Bacharova L, Fandakova K, Bratinka J, Budinska M, Bachar J, Gud-aba M. The association between air pollution and the daily number of deaths: findings from the Slovak Republic contribution to the APHEA project. *J Epidemiol Community Health* 1996; 50: Suppl. 1, S19-S21.
5. Schouten JP, Vonk JM, de Graaf A. 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. *J Epidemiol Community Health* 1996; 50: Suppl. 1, S22-S29.
6. Zmirou D, Barumandzadeh T, Balducci F, Ritter P, Laham G, Ghilardi JP. Short term effects of air pollution on mortality in the city of Lyon, France, 1985-90. *J Epidemiol Community Health* 1996; 50: Suppl. 1, S30-S35.
7. Wojtyniak B, Piekarski T. Short term effect of air pollution on mortality in Polish urban populations - what is different? *J Epidemiol Community Health* 1996; 50: Suppl. 1, S36-S41.
8. Dab W, Medina S, Quenel P, *et al.* Short term respiratory health effects of ambient air pollution: results of the APHEA project in Paris. *J Epidemiol Community Health* 1996; 50: Suppl. 1, S42-S46.
9. Touloumi G, Samoli E, Katsouyanni K. Daily mortality and "winter type" air pollution in Athens, Greece - a time series analysis within the APHEA project. *J Epidemiol Community Health* 1996; 50: Suppl. 1, S47-S51.
10. Spix C, Wichmann HE. Daily mortality and air pollutants: findings from Koln, Germany. *J Epidemiol Community Health* 1996; 50: Suppl. 1, S52-S58.
11. Ponka A, Virtanen M. Asthma and ambient air pollution in Helsinki. *J Epidemiol Community Health* 1996; 50: Suppl. 1, S59-S62.
12. Vigotti MA, Rossi G, Bisanti L, Zanobetti A, Schwartz J. Short term effects of urban air pollution on respiratory health in Milan, Italy, 1980-89. *J Epidemiol Community Health* 1996; 50: Suppl. 1, S71-S75.
13. Anderson HR, Spix C, Medina S, *et al.* Air pollution and daily admissions for chronic obstructive pulmonary disease in 6 European cities: results from the APHEA project. *Eur Respir J* 1997; 10: 1064-1071.
14. Katsouyanni K, Touloumi G, Spix C, *et al.* Short-term effects of ambient sulphur dioxide and particulate matter on mortality in 12 European cities: results from time series data

- from the APHEA project. Air Pollution and Health: a European Approach. *BMJ* 1997; 314: 1658–1663.
15. Touloumi G, Katsouyanni K, Zmirou D, *et al.* Short-term effects of ambient oxidant exposure on mortality: a combined analysis within the APHEA project. Air Pollution and Health: a European Approach. *Am J Epidemiol* 1997; 146: 177–185.
 16. Sunyer J, Spix C, Quenel P, *et al.* Urban air pollution and emergency admissions for asthma in four European cities: the APHEA Project. *Thorax* 1997; 52: 760–765.
 17. Spix C, Anderson HR, Schwartz J, *et al.* Short-term effects of air pollution on hospital admissions of respiratory diseases in Europe: a quantitative summary of APHEA study results. Air Pollution and Health: a European Approach. *Arch Environ Health* 1998; 53: 54–64.
 18. Zmirou D, Schwartz J, Saez M, *et al.* Time-series analysis of air pollution and cause-specific mortality. *Epidemiology* 1998; 9: 495–503.
 19. Anderson HR, Quenel P, Katsouyanni K, *et al.* Recommendations for the monitoring of short-term health effects of air pollution: lessons from the APHEA Multi Centre European Study. *Zentralbl Hyg Umweltmed* 1999; 202: 471–488.
 20. Hasford B, Fruhmann G. Air pollution and daily admissions for chronic obstructive pulmonary disease in six European cities: results from the APHEA project. Air Pollution and Health, a European Approach. *Eur Respir J* 1998; 11: 992–993.
 21. Vigotti MA. Short-term effects of exposure to urban air pollution on human health in Europe. The APHEA Projects (Air Pollution and Health: a European Approach). *Epidemiol Prev* 1999; 23: 408–415.
 22. Samoli E, Schwartz J, Wojtyniak B, *et al.* Investigating regional differences in short-term effects of air pollution on daily mortality in the APHEA project: a sensitivity analysis for controlling long-term trends and seasonality. *Environ Health Perspect* 2001; 109: 349–353.
 23. Ben-David A, Ifarraguerrri A. Computation of a spectrum from a single-beam fourier-transform infrared interferogram. *Appl Opt* 2002; 41: 1181–1189.
 24. Wong TW, Tam WS, Yu TS, Wong AH. Associations between daily mortalities from respiratory and cardiovascular diseases and air pollution in Hong Kong, China. *Occup Environ Med* 2002; 59: 30–35.
 25. Biggeri A, Bellini P, Terracini B. Meta-analysis of the Italian studies on short-term effects of air pollution. *Epidemiol Prev* 2001; 25: Suppl. 2, 1–71.
 26. Wong CM, Ma S, Hedley AJ, Lam TH. Effect of air pollution on daily mortality in Hong Kong. *Environ Health Perspect* 2001; 109: 335–340.
 27. Ballester Diez F, Saez Zafra M, Alonso Fustel ME, *et al.* The EMECAM project: the Spanish Multicenter Study on the Relationship between Air Pollution and Mortality. The background, participants, objectives and methodology. *Rev Esp Salud Publica* 1999; 73: 165–175.
 28. Saez M, Perez-Hoyos S, Tobias A, Saurina C, Barcelo MA, Ballester F. Time series methods in epidemiological studies on air pollution. *Rev Esp Salud Publica* 1999; 73: 133–143.
 29. Tobias Garces A, Sunyer Deu J, Castellsague Pique J, Saez Zafra M, Anto Boque JM. Impact of air pollution on the mortality and emergencies of chronic obstructive pulmonary disease and asthma in Barcelona. *Gac Sanit* 1998; 12: 223–230.
 30. Tenias JM, Ballester F, Rivera ML. Association between hospital emergency visits for asthma and air pollution in Valencia, Spain. *Occup Environ Med* 1998; 55: 541–547.
 31. Hasford B, Fruhmann G. Air pollution and daily admissions for chronic obstructive pulmonary disease in six European cities: results from the APHEA project. Air Pollution and Health, a European Approach. *Eur Respir J* 1998; 11: 992–993.
 32. Simpson RW, Williams G, Petroschevsky A, Morgan G, Rutherford S. Associations between outdoor air pollution and daily mortality in Brisbane, Australia. *Arch Environ Health* 1997; 52: 442–454.
 33. Ballester F, Corella D, Perez-Hoyos S, Hervas A. Air pollution and mortality in Valencia, Spain: a study using the APHEA methodology. *J Epidemiol Community Health* 1996; 50: 527–533.
 34. Department of Health. Committee on the Medical Effects of Air Pollution. Non-biological particles and health. London, HMSO, 1995.
 35. Samet J, Zeger S, Dominici F, *et al.* Morbidity and Mortality from air pollution in the United States. Final Report NMMAPS. Cambridge, MA, Health Effects Institute, 2000.
 36. U.S. Environmental Protection Agency Office of Air Quality Planning and Standards. Review of the national ambient air quality standards for particulate matter: policy assessment of scientific and technical information. QAQPS Staff Paper. EPA-45/R-1996: 96-013. Research Triangle Park, NC, U.S. EPA Office of Air Quality Planning and Standards, 1996.
 37. Commission of the European Communities. Council Directive 96/2/EC on ambient air quality assessment and management. *Official J Eur Communities* 1996; 21.11.96 NOL 296/55.
 38. Pope CA 3rd. Epidemiology of fine particulate air pollution and human health: biologic mechanisms and who's at risk? *Environ Health Perspect* 2000; 108: Suppl. 4, 713–723.
 39. Katsouyanni K, Touloumi G, Samoli E, *et al.* Confounding and effect modification in the short-term effects of ambient particles on total mortality: Results from 29 European cities within the APHEA2 project. *Epidemiology* 2001; 12: 521–531.
 40. Atkinson RW, Anderson HR, Sunyer J, *et al.* Acute effects of particulate air pollution on respiratory admissions: results from APHEA 2 project. Air Pollution and Health: a European Approach. *Am J Respir Crit Care Med* 2001; 164: 1860–1866.
 41. Zanobetti A, Schwartz J, Samoli E, *et al.* The temporal pattern of mortality responses to air pollution: a multi-city assessment of mortality displacement. *Epidemiology* 2002; 13: 87–93.
 42. Gouveia N, Fletcher T. Time series analysis of air pollution and mortality: effects by cause age and socio-economic status. *J Epidemiol Community Health* 2000; 54: 750–755.
 43. Levy JI, Hammitt JK, Spengler JD. Estimating the mortality impacts of particulate matter: what can be learned from between-study variability? *Environ Health Perspect* 2000; 108: 109–117.
 44. Goldberg MS, Bailar JC 3rd, Burnett RT, *et al.* Identifying subgroups of the general population that may be susceptible to short-term increases in particulate air pollution: time-series study in Montreal, Quebec. *Res Rep Health Eff Inst* 2000; 97: 7–113.