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Effects of the Asian Dust Events on Daily Mortality in Seoul, Korea

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The Korean peninsula has a long history of dust clouds blown by winds from the arid deserts of Mongolia and China in springtime; these are called Asian dust events. Public concern about the possible adverse effects of this dust has increased, because the dust arrives in Korea after having passed over heavily industrialized eastern China. The present study explored the effect of Asian dust events on daily mortality in Seoul, South Korea, during the period 1995–1998. We evaluated the association between daily death counts and the dust events using Poisson regression analysis, adjusted for time trends, weather variables, and the day of the week. Between 1995 and 1998, we identified 28 Asian dust days in Seoul. The estimated percentage increase in the rate of deaths from 3-day moving averages of exposure was 1.7% (95/ confidence interval: −1.6 to 5.3) for all causes, 2.2% (95% confidence interval: −3.5 to 8.3) for deaths of persons aged 65 years and older, and 4.1% (95% confidence interval: −3.8 to 12.6) for cardiovascular and respiratory causes. Our results provide weak evidence that the Asian dust events are associated with risk of death from all causes. However, the association between the dust events and deaths from cardiovascular and respiratory causes was stronger and it suggests that persons with advanced cardiovascular and respiratory disease may be susceptible to the Asian dust events.

Key Words: **Asian dust events; PM_{10}; daily mortality; Poisson regression analysis; Seoul.**

INTRODUCTION

Wind-blown dust originating from the arid of deserts Mongolia and China is a well-known springtime meteorological phenomenon throughout East Asia. Sometimes this dust is transported across the Pacific and it has been detected on the western coast of North America (Husar *et al*., 2001). It starts with a dust storm in Mongolia and China and appears as a distinct yellow cloud in Korea. This event has a long history, long enough to have earned it the local name *whangsa*, which means "yellow sand" in Korean. Many Koreans are worried about the possible adverse health effects of this dust event, and these concerns have increased because the dust arrives in Korea after having passed over heavily industrialized eastern China (Yoon, 2000). Kim *et al*. (2001) report that a significant amount of SO_2 converts to sulfate during the long-range transport from China to Korea.

Many studies have suggested that the effects of particulate air pollution on daily deaths are due primarily to fine combustion particles (Laden *et al*., 2000; Pope *et al*., 1999; Schwartz *et al*., 1996, 1999; Willson and Suh, 1997). The dust in the Asian dust event, which is composed primarily of coarse crust-derived particles in origin, may possibly carry toxic materials from combustion sources in Eastern China to Seoul, South Korea. This study was planned to investigate the possible effects of the Asian dust events on the mortality of residents in Seoul, South Korea, during the period 1995–1998.

MATERIALS AND METHODS

Study Population

The numbers of total nonaccidental deaths per day occurring in Seoul between 1995 and 1998 were extracted from the mortality records supplied by the National Statistical Office. A time series of the daily count of deaths for all age groups and all causes of death, but excluding deaths caused by accidents (ICD 10th revision V01-Y89) was prepared. Mortality

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in persons younger than 65 and mortality in persons 65 and older were determined seperately. Daily counts of mortality were also subdivided by cause of death. The causes analyzed were cardiovascular and respiratory disease (ICD 10th revision I00-I99 and J00-J98) and other causes.

Air Pollution, Weather, and Asian Dust

Hourly measures of carbon monoxide, nitrogen dioxide, sulfur dioxide, and PM_{10} were obtained from monitoring stations distributed evenly throughout Seoul. Daily information on mean temperature and mean relative humidity were provided by the Korea Meteorological Administration from a station located in central Seoul. Additional details on air pollutant measurements and meteorological records have been described elsewhere (Kwon *et al*., 2001).

Analysis

To characterize the Asian dust events, we chose control days that included all the days in spring (March, April, May) during the study period except the Asian dust event days. Average levels of air pollutants, weather variables, and death counts on the Asian dust days were compared with those on control days. We used the general additive model (GAM) approach with Poisson log-linear regression. Initially, we developed a basic model to accommodate variations in the data, and used a locally weighted (loess) smoothing technique to control for seasonal variations and meteorological variables. We fitted the simplest model with a loess smooth of the time variable, determining the smoothing parameter that minimized Akaike's information criteria (AIC). To control for seasonal variations and time trends, the time span specified for smoothing parameters needed to be small, because there was usually a periodic pattern within each of the years. However, we did not use a span below 5% of the study period, even if there was a further improvement in the AIC. As suggested elsewhere (Schwartz, 1999), specifying an excessively small time span would tend to fit patterns of short duration, which could be due to dust events.

Thereafter, weather terms were incorporated into the model (temperature and relative humidity on the same day). For the smooth function of temperature and relative humidity, we used loess functions with the span of 50%. We also included dummy variables for days of the week. To reduce the influence of outliers in mortality, a robust Poisson regression was used. Once the basic explanatory variables had been decided, we added dummy variables for the dust events. The effects of dust events, if any, might be delayed or manifested over a period of several days. To accommodate such patterns, we used single-day lags of up to 3 days and 3-day moving averages of exposure on the same day and the 2 previous days. To obtain the average exposure for the moving average, the dust event was treated as an integer variable. We also fitted the model with a 3-day moving average of death counts on the event day and the 2 following days.

All analyses were performed using the *gam*( ) function of the S-plus statistical software package.

RESULTS

Between 1995 and 1998, we identified 28 Asian dust days in Seoul during spring (Table 1). The average PM_{10} concentration on the event days was 101.1 μg/m^3, which was 27.8 μg/m^3 higher than that on the control days. The levels of other pollutants such as CO, NO_2, SO_2, and ozone were very similar, though the temperature and relative humidity were slightly lower during the event days (Table 2).

The associations between the dust event and mortality across the various lags are summarized in Table 3. The pattern of lag effects varied according to the cause of death (Table 3). With respect to deaths from all causes, the effect of the dust event was prominent 2 days after the event. When analysis was restricted to deaths in persons 65 years and older, the effect size appeared stronger than total deaths with a similar lag pattern. For cardiovascular and respiratory deaths, the association was highest on the event day and decreased thereafter. Deaths from all causes except cardiovascular and respiratory causes showed negative association with the dust event on the same and 1-day lag. The estimated percentage increase in the rate of deaths from 3-day

TABLE 1
Asian Dust Days in Seoul, South Korea, 1995–1998

Year	Date
1995	7–9 April
	18 April
	23–26 April
	28April–2 May
1996	8 May
1997	30 March
1998	28–30 March
	14–22 April
	28 April

TABLE 2

Daily Averages of Environmental Levels and Death counts on Asian Dust Days and Control Days in Seoul, South Korea, 1995–1998

Variable[a]	Asian dust days	Control days
PM_{10}(μg/m³)	101.1(29.5)**	73.3(27.7)
CO(100 ppb)	11.5(2.9)	11.4(3.1)
NO_2(ppb)	35.5(10.5)	33.5(9.3)
SO_2(ppb)	14.5(7.7)	13.1(6.2)
O_3(ppb)	20.0(4.7)	19.0(6.2)
Temperature (°C)	12.0(5.9)*	14.6(4.0)
Humidity(%)	56.0(13.2)	58.3(14.7)
Daily deaths from all causes(count)	88.4(10.8)	91.5(10.8)
Daily deaths ≥ 65	53.9(9.3)	56.3(8.5)
Daily deaths from CV and respiratory causes[b]	32.3(5.2)	31.8(6.0)

[a]Values are 24-h averages.
[b]Deaths from cardiovascular causes (ICD10 I00-I99) and respiratory causes (ICD10 J00-J98).
*$P<0.05$, **$P<0.01$, using *t* test.

moving averages of exposure was 1.7% for all causes, 2.2% for deaths in persons 65 years and older, 4.1% for cardiovascular and respiratory causes, and − 0.1% for other causes of death.

Estimate of percentage increase from the 3-day moving average of death counts was 1.2% (95% CI: − 1.2 to 3.6%) for all causes, 1.9% (95% CI: − 1.0 to 4.9) for deaths in persons 65 years and older, and 2.5% (95% CI: − 2.3 to 7.5%) for cardiovascular and respiratory causes (Fig. 1).

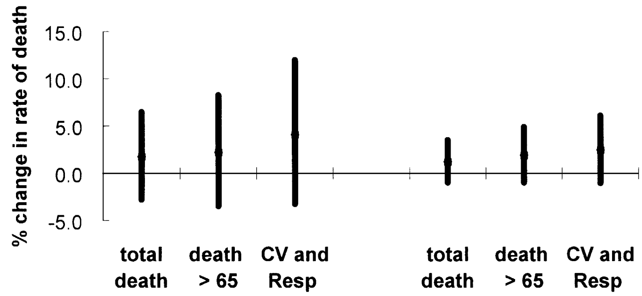

FIG. 1. Percentage increases in the risk of death from all causes, death in the aged (≥ 65), and death from cardiovascular and respiratory causes, estimated using 3-day moving average of exposure (left) and 3-day moving average of death counts (right).

DISCUSSION

The adverse effects of the Asian dust event, if any, probably are manifested across several of the following days. A method commonly used to accommodate the time lags between an air pollution event and a health effect involves the use of models incorporating multiday moving averages of pollutants (Katsouyanni *et al*., 1997; Kelsall *et al*., 1997). Recently, more sophisticated methods like the polynomial distributed lag model have also been introduced into air pollution epidemiology (Gold *et al*., 1999; Schwartz, 2000). When the exposure variable is dichotomous as is this dust event, it seems reasonable to take the moving average of death counts to reflect lagged effect of the exposure. In our study, the model with

TABLE 3

Estimated Percentage Increases in the Risk of Death and 95% Confidence Intervals Associated with Asian Dust Events across the Various Lags

	Same day	1-Day lag	2-Day lag	3-Day lag	3-Day Moving average
Age					
< 65	− 2.5	− 0.3	1.1	0.7	− 1.0
	(− 8.3, 3.6)	(− 6.2, 5.9)	(− 4.8, 7.3)	(− 5.1, 6.9)	(− 7.7, 6.2)
≥ 65	− 1.1	− 0.0	5.3	− 0.7	2.2
	(− 6.0, 4.1)	(− 4.9, 5.1)	(0.3, 10.5)	(− 5.4, 4.3)	(− 3.5, 8.3)
Cause of death					
All causes	− 0.3	0.2	3.4	− 1.1	1.7
	(− 4.2, 3.7)	(− 3.6, 4.3)	(− 0.5, 7.4)	(− 4.8, 2.9)	(− 2.8, 6.5)
CV and respiratory causes[a]	3.7	2.1	2.1	− 5.6	4.1
	(− 2.7, 10.5)	(− 4.2, 8.8)	(− 4.2, 8.8)	(− 11.5, 0.7)	(− 3.3, 12.0)
Other causes[b]	− 2.6	− 1.4	3.9	1.0	− 0.1
	(− 7.1, 2.1)	(− 5.9, 3.4)	(− 0.8, 8.8)	(− 3.6, 5.9)	(− 5.4, 5.5)

[a]Deaths from cardiovascular causes (ICD10 I00-I99) and respiratory causes (ICD10 J00-J98).
[b]All nonaccidental deaths except cardiovascular and respiratory causes.

3-day moving averages of death counts produced smaller effect estimates than the model with 3-day moving averages of the dust event. However, the effect estimates from the model with moving averages of death counts were more precise, as expected when the variability of the outcome variable is reduced, by using the average of death counts for 3 days, rather than reducing the variability of the exposure variable as in the prior approach. Further mathematical consideration should be given to the use of taking outcome variable averages to accommodate lagged effects of air pollution.

In general, our results provided weak evidence that the Asian dust event is associated with an increased risk of mortality. However, the sizes of the effect estimates were quite similar to those obtained by other studies on the association between PM_{10} and mortality. The difference between PM_{10} concentrations on the event days and control days was 27.8 $\mu g/m^3$ ($P < 0.01$). We observed a 1.7% increase in the risk of death from all causes during the dust events, which amounts to a 0.6% increase in the death rate for each 10 $\mu g/m^3$ increase in PM_{10} concentration.

Samet *et al.* (2000) reported an average increase in the rate of death due to all causes of about 0.5% for a 10 $\mu g/m^3$ increase in PM_{10} concentration. Studies conducted in South Korea have shown similar results. For each increase of 10 $\mu g/m^3$ in PM_{10} on the same day, Kwon *et al.* (2001) reported a 0.3% increase in the rate of death from all causes, in a study conducted in Seoul during 1994–1998. Hong *et al.* (1999) reported a 0.8% increase in deaths from all causes for the same increase in the 5-day PM_{10} moving average, in a study conducted in Inchon, located near Seoul.

The dust events had a greater effect on the rate of death in the aged and death from cardiovascular and respiratory causes than on death from all causes. This pattern of deaths is consistent with other studies showing that the elevated risk of death associated with short-term increases in particles is due primarily to respiratory and cardiovascular mortality (Kwon *et al.*, 2001; Schwartz, 1994; Sunyer *et al.*, 2000; Zmirou *et al.*, 1998). Even though the risk estimates of the dust events did not achieve statistical significance, it can be hypothesized that the Asian dust events increase the risk of death by involving a cardiovascular mechanism.

There are just a few epidemiologic studies of the acute effects of coarse-mode particles (Gordian *et al.*, 1996; Ostro *et al.*, 1999). Many studies have suggested that combustion-source particles are more associated with increased mortality than crustal particles (Laden *et al.*, 2000; Pope *et al.*, 1999; Schwartz *et al.*, 1996, 1999; Wilson and Suh, 1997). Assessments of the health implications of coarse particles have been performed, in part by examining episodes of high concentrations of coarse particles (Pope *et al.*, 1999; Schwartz *et al.*, 1999). Episodes of high levels of airborne coarse particles are usually related to high wind speed, which may tend to decrease the concentrations of other air pollutants and have people stay indoors. These Asian dust events differ in some ways from other dust storm events. First, the average particle size may be much smaller because large particles are preferentially removed by gravity during their long journey from their source to Korea. Chun *et al.* (2001) have reported that the dust from the Asian dust event is in the size range between 1.35 and 10 μm. Second, the average concentrations of other pollutants during the Asian dust events are not different from those on control days because event days are associated with a dust cloud rather than a dust storm with high wind speeds. It is likely that the dust is mixed with other toxic materials in the air of Seoul. The concentration of sulfate in major Korean cities appeared to be increased during the Asian dust event (Lee *et al.*, 1993). One study on the chemical composition of the aerosol in Seoul showed that concentrations of lead, NO_3^-, and SO_4^{2-} increased during the dust event (Choi *et al.*, 2001).

CONCLUSION

The dust in the Asian dust events could increase the risk of mortality, as it may act as a vector for other toxic materials such as sulfate and nitrate. The finding that the association between the dust events and daily mortality was stronger for cardiovascular and respiratory causes supports this hypothesis.

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