Coarse particles and mortality: evidence from a multi-city study in California

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ABSTRACT

Objective: To examine the risk of all-cause and cardiovascular mortality associated with short-term coarse particle exposure in California while addressing issues of exposure misclassification by limiting the study to those residing near a pollution monitor.

Methods: Deaths in 15 California counties from 1999 to 2005 were linked to coarse particulate monitoring data. Case deaths were limited to those residing in a zip code within 20 km of a pollution monitor. We used conditional logistic regression with a case-crossover design to estimate county-specific effects of coarse particles. County estimates were then pooled using random-effects meta-analysis to create overall study estimates. Effects specific to race and educational status were also analysed.

Results: We observed an increased excess risk (ER) of both all-cause mortality (ER per 10 $\mu g/m^3$ = 0.7%, 95% CI −0.1 to 1.5) and cardiovascular mortality (ER per 10 $\mu g/m^3$ = 1.3%, 95% CI 0.1 to 2.5) from a 2-day lag in coarse particles. Greater effects were observed among Hispanics and non-high school graduates. Adjustment for fine particles and decreasing the inclusion buffer to 10 km did not substantively alter the results.

Conclusions: Our study provides further evidence of an association between acute exposure to coarse particles and mortality, and supports the hypothesis that lower socioeconomic status groups may be more susceptible to its effects.

What this paper adds

- Evidence connecting coarse particles with mortality is limited and there is a need for more large multi-site studies.
- Issues involving the spatial heterogeneity of coarse particles, confounding due to fine particles, and effect modification by individual-level factors could have influenced previous findings, and should be explored in more depth.
- In this study, exposure to ambient coarse particles in California is associated with premature all-cause and cardiovascular mortality, with little evidence of confounding due to fine particles.
- Individuals of lower educational attainment and Hispanic race/ethnicity, both likely proxies of lower socioeconomic status, demonstrated greater effects when compared with corresponding individuals of higher educational attainment and non-Hispanic Whites, respectively.
- Regulatory control of coarse particles may provide important health benefits, and current pollution control policies should consider these potential risks and the likelihood that economically disadvantaged groups may be disproportionately impacted.

Research published within the last year has addressed the association between hospital admissions for cardiovascular and respiratory diseases and levels of coarse particles (particulate matter between 2.5 and 10 microns in aerodynamic diameter or $PM_{10-2.5}$).[1 2] However, there have been few recent published studies on the relationship between coarse particles and mortality, and studies that are currently available do not reach a clear consensus on whether an association exists.[3] Considering the fact that many studies have linked fine particles ($PM_{2.5}$) with both mortality and morbidity, and that the inflammatory mechanisms through which $PM_{2.5}$ is known to incite cardiovascular distress are also promoted by coarse particle exposure,[4–7] it is a reasonable hypothesis that coarse particle effects should manifest in exposed populations. The US Environmental Protection Agency (EPA) has noted the need for a larger body of evidence for health effects from coarse particles, and has established it as a priority ahead of its next PM Standard Review.[8] Thus, contributions to the coarse particle literature are needed to help discern those effects and better inform upcoming regulatory decisions.

Previous literature on coarse particles and mortality has raised a few issues. One is that coarse particle findings could be confounded by fine particles. A review by Brunekreef and Forsberg[3] noted that most mortality studies utilising two pollutant estimates were unable to demonstrate independent coarse particle effects after adjustment for fine particles, raising concern as to whether observed coarse particle effects in other studies might be related to their correlation with fine particles. Furthermore, coarse particle levels are also more spatially heterogeneous than fine particle levels,[9] increasing the likelihood of exposure misclassification in monitor-based studies. This may be of particular concern for the previous multi-site studies conducted in the Eastern USA and Canada,[10 11] where coarse particle levels are fairly low and thus more likely to be impacted by exposure error. Additionally, most of the epidemiological studies examining mortality have centred on a single city or local region and have ranged in location from Detroit, USA[12] to Santiago, Chile[13] and Shanghai, China.[14] Differences in observed effects between the studies could be due to differences in demographic characteristics, such

as population age distribution, or coarse particle composition (ie, urban vs rural) in each city.

Our study examines the risk of all-cause and cardiovascular mortality associated with short-term coarse particle exposure in California, where coarse particle concentrations vary widely and tend to be uncorrelated with fine particle concentrations. Additionally, we seek to minimise exposure misclassification that may have influenced previous findings through restriction of the study population to those residing within a fixed distance from a pollution monitor. Also, our individual-level demographic data allow for examination of specific subpopulations. Previous studies have shown that differences in health impacts of PM_{10} and $PM_{2.5}$ occur among age, racial/ethnic, and socioeconomic populations,[15–18] and may exist for coarse particles as well.[19]

METHODS

Mortality data

Mortality cases were selected from a database of California deaths from 1999 to 2005 provided by the California Department of Public Health, Center for Health Statistics. This database provided individual-level information on a decedent's age, race/ethnicity, educational background, underlying cause of death, zip code of residence, and county of death as extracted from death certificates. Cases were limited to those who died in their county of residence in order to select for individuals for which residence-based coarse particle estimates were most likely to represent exposures prior to death. Also, to reduce exposure misclassification, we only included cases whose zip code population centroid was located within 20 km of an air monitor with collocated PM_{10} and $PM_{2.5}$ measurements. This distance was chosen since, for our California coarse particle data, correlations between monitors greater than this distance were poorer. Within 10 km, the median correlation between coarse particle monitors was 0.81, while monitors within 20 km had a median correlation of 0.75. Beyond 20 km, the inter-monitor correlations consistently decreased. For all-cause mortality analyses, cases were limited to non-external causes of death (ICD-10 codes A00-R99). Cardiovascular mortality analyses only included cases in which their underlying cause of death had an ICD-10 code from I00-I99.

Pollutant and meteorological data

Data on airborne particle levels were provided by the California Air Resources Board. Coarse particle levels were not directly measured, so 24 h average concentrations of $PM_{2.5}$ were subtracted from collocated 24 h average concentrations of PM_{10} to calculate coarse particle levels in micrograms per meter cubed ($\mu g/m^3$). This resulted in occasional negative values for approximately 1% of the calculated coarse particle readings. These measurements were excluded from the dataset. Coarse particle calculations were generally available every sixth day. Daily temperature and relative humidity data were retrieved from the AIRS-AQS database, compiled by the US EPA, and the California Irrigation Management Information System, provided by the California Department of Water Resources. These meteorology data were available on a daily basis. Each case was assigned the nearest air pollution and temperature monitor with available readings for that time period, based on the population centroid of their zip code of residence. Location-based assignment was performed using ArcGIS V.9.0 with Hawth's Tools.

Study design and statistical analysis

To execute a time-stratified case-crossover design, each case day was assigned referent days comprised of all other available coarse particle readings from the same month and year. This method inherently reduces bias associated with long-term and seasonal trends in temperature and pollution when compared with retrospective designs.[20] The majority of cases had four or five controls as is consistent with the common one-in-six day sampling schedule for coarse particles. Case-control groups were aggregated by county of residence, and conditional logistic regression models were run using PROC PHREG in SAS V.9.1 to calculate county-specific estimates of effect. We separately evaluated effects related to coarse particle levels on the same day, and on 1 and 2 days prior to, the day of death. These final models adjusted for weather (mean temperature and relative humidity) using a 1-day lag, and for day of week. County estimates were then combined to obtain an overall effect estimate using a random-effects meta-analysis procedure in R 2.5.0.[21] Results are presented in terms of per cent excess risk (ER) per 10 $\mu g/m^3$ increase in coarse particles ((odds ratio per 10 $\mu g/m^3$ increase -1) $\times 100$). To investigate potentially susceptible subpopulations, we ran analyses stratified by education (high school graduates vs non-high school graduates), race/ethnicity (Whites vs Hispanics), age ($\geq$65 years), and sex. Both education and race/ethnicity were of interest because they can serve as markers for socioeconomic status (SES). Our definition of Hispanic and White populations corresponds to US Census definitions of Hispanics and non-Hispanic Whites. In our study area, Hispanic cases are comprised of 81% of persons of Mexican/Chicano background, 2% Puerto Rican, 2% Cuban, and 9% Central and South American, proportions which reflect the California Hispanic population as a whole. Where specified, the t value was used to assess the significance of differences between estimates of corresponding demographic groups, as has been carried out in previous air pollution studies.[19]

Our sensitivity analyses included: (1) using models adjusting for $PM_{2.5}$ levels; and (2) decreasing the radius of case inclusion to within 10 km of a coarse particle monitor. For the models that included both fine and coarse particles together, a similar lag was used for the pollutants.

RESULTS

The 15 counties used in this analysis covered a wide range of coarse particle levels, with mean daily coarse particle levels ranging from 10.6 $\mu g/m^3$ in Alameda County to 46.5 $\mu g/m^3$ in Imperial County (table 1). Figure 1 provides a description of the location of the monitors and counties in the study. Counties also differed meteorologically, with mean daily temperatures ranging from 57.2°F in San Francisco County to 72.2°F in Imperial County. Correlations between coarse and fine particles for these counties ranged from -0.03 in Fresno to 0.35 in San Francisco. Eligible cases with all covariate data numbered 107 188, with 45 036 of those deaths due to cardiovascular causes. Table 2 provides a demographic breakdown of cases by county. All-cause cases included notable percentages of Hispanics (14%) and non-high school graduates (27%). These cases were also 48% male and 77% aged $\geq$65 years. When the buffer size for study inclusion was reduced to 10 km, 64 066 total cases and 26 801 cardiovascular cases were analysed.

The relationship between coarse particles and all-cause mortality using a 20 km buffer approached statistical significance (ER per 10 $\mu g/m^3$ = 0.7%, 95% CI -0.1 to 1.5) when using a 2-day lag (fig 2). When examining specific demographics for this lag, the strongest association was seen among non-high

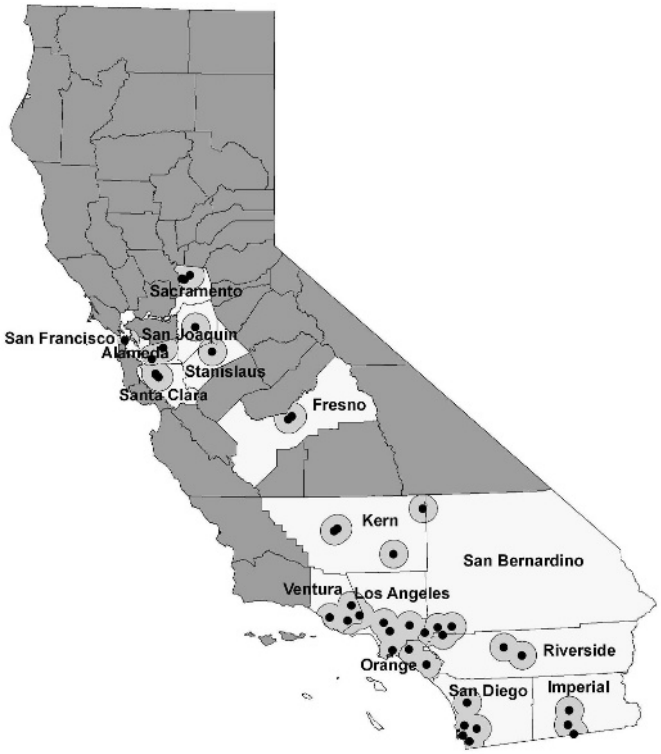

Figure 1 Map of California coarse particle monitoring sites and study area boundaries for 20 km inclusion buffer analyses.

school graduates (ER = 2.2%, 95% CI 0.7 to 3.6), whereas little association was observed among high school graduates (ER = 0.2%, 95% CI −0.8 to 1.2). Coarse particles were found to be significantly associated with mortality among Whites, and elevated risks were also observed for females (fig 2; also refer to online supplement).

Focusing the analysis on cardiovascular mortality showed a statistically significant increase in risk associated with coarse particles in the overall population for a 2-day lag (ER per 10 μg/m^3 = 1.3%, 95% CI 0.1 to 2.5) (fig 3). Stratification by demographic groups also identified significant associations among certain subgroups. More specifically, significant ERs of cardiovascular mortality were observed for both Hispanics and Whites, non-high school graduates, and females (fig 3; also refer to online supplement). Effect estimates for males and those aged ⩾65 years also approached statistical significance. Unlagged coarse particle effects were significantly higher for Hispanics (ER = 4.7%, 95% CI 1.4 to 8.0) when compared with Whites at the same lag (ER = −0.3%, 95% CI −1.9 to 1.3) (p value for the difference = 0.01). A 2-day lag between coarse particle levels and mortality generated the strongest effects among Whites, but the ER for Hispanics observed at this lag was still greater. More than double the ER was observed for non-high school graduates using a 2-day lag (ER = 2.5%, 95% CI 0.3 to 4.7) compared with corresponding high school graduates. Effects differed by gender, with males showing greater same-day effects while females showed higher effects using a 2-day lag.

Adjustment for $PM_{2.5}$ reduced the precision of these findings slightly but had little impact on the magnitude of effect, despite significant associations between $PM_{2.5}$ and mortality. Mortality associations with coarse particles remained significant or near-significant for Hispanics, Whites, non-high school graduates, females and adults aged ⩾65 years, as well as for the entire dataset (figs 2 and 3; also refer to online supplement). Similar estimates were also observed when the radius of study inclusion was reduced to 10 km (figs 2 and 3).

DISCUSSION

In our multi-county, case-crossover study, we observed significant associations between coarse particles and both all-cause and cardiovascular mortality. For both outcomes, the magnitude of these associations were greater among two lower SES groups, Hispanics and non-high school graduates, when compared with Whites and high school graduates, respectively. In general, neither the restriction of study area to within 10 km

Table 1 Descriptive statistics by county, 1999–2005

County	Mean CP (25th and 75th percentile) (μg/m^3)	Mean absolute difference in CP between cases and controls/IQR for difference (μg/m^3)	Mean $PM_{2.5}$ (μg/m^3)	Correlation between CP and $PM_{2.5}$	Mean temperature (°F)	Mean RH (%)	Non-injury cases*	Cardiovascular cases*
Alameda	10.6 (6.5, 13.7)	5.2/5.2	11.1	0.09	57.4	71.7	6598	2744
Fresno	19.7 (9.0, 26.5)	7.4/7.0	18.8	−0.03	61.9	61.6	3954	1692
Imperial	46.5 (29.8, 52.8)	23.7/18.1	11.9	0.27	72.2	48.5	459	185
Kern	23.2 (11.8, 30.8)	10.5/10.9	17.0	0.16	64.0	57.0	3516	1576
Los Angeles	16.7 (11.0, 21.7)	6.3/6.3	17.1	0.11	62.7	65.9	29 753	12 944
Orange	14.2 (8.8, 17.7)	6.7/6.1	14.5	0.12	62.5	69.6	8451	3678
Riverside	32.0 (21.3, 39.5)	12.0/12.2	16.9	0.11	68.0	50.9	5383	2274
Sacramento	12.3 (7.0, 15.5)	5.2/4.9	12.4	0.07	61.2	66.9	6956	2983
San Bernardino	23.9 (15.3, 32.9)	9.9/10.1	17.3	0.05	62.6	47.4	3585	1391
San Diego	15.9 (10.9, 19.7)	6.6/6.4	14.1	0.03	61.0	72.6	15 137	6076
San Francisco	13.0 (7.5, 16.8)	6.2/6.2	11.1	0.35	57.2	70.2	5363	2111
San Joaquin	17.5 (10.0, 22.0)	7.9/7.7	14.5	0.09	60.2	67.2	3434	1537
Santa Clara	14.2 (9.4, 17.9)	5.6/5.9	12.3	0.29	58.2	69.4	8089	3163
Stanislaus	16.5 (9.0, 20.0)	7.2/6.5	16.9	0.02	59.2	67.6	2783	1216
Ventura	15.4 (9.8, 19.8)	7.4/6.7	12.3	0.16	60.5	68.9	3727	1466
Totals							107 188	45 036

*Based on a 0-day lag in coarse particles from a monitor within 20 km.
CP, coarse particles; IQR, interquartile range; $PM_{2.5}$, fine particles; RH, relative humidity.

Table 2 Demographic breakdown of non-injury mortality cases by county

County	Non-HS graduates (%)	HS graduates (%)	Hispanics (%)	Whites (%)	Males (%)	Aged ⩾65 years (%)
Alameda	25	70	8	58	47	75
Fresno	34	62	17	70	48	77
Imperial	57	36	57	37	59	80
Kern	33	62	13	77	49	74
Los Angeles	30	63	20	56	48	75
Orange	22	75	11	79	46	81
Riverside	26	69	16	75	50	77
Sacramento	24	72	6	77	48	76
San Bernardino	35	58	23	63	49	70
San Diego	22	74	11	78	48	79
San Francisco	25	67	8	52	53	74
San Joaquin	38	58	13	69	49	74
Santa Clara	24	72	12	70	48	79
Stanislaus	36	61	9	86	46	77
Ventura	22	75	15	79	46	80

HS, high school.

of a monitor location nor the inclusion of fine particles in our regression models qualitatively altered our findings.

Our findings using the case-crossover design provide some support to several previous time-series studies which have found significant effects on all-cause mortality associated with coarse particles, including studies undertaken in Phoenix[22]; Coachella Valley, California[23]; Canada[10]; Santiago, Chile[13] and Mexico City.[24] The 1% increase in ER in our unadjusted analysis is similar to those observed in the larger mortality studies.[25] However, unlike previous studies which reported results from two pollutant models, fine particle levels did not appear to be a powerful confounder in our all-cause mortality analysis.

Our study is one of the few to also report results on cardiovascular mortality. The focus on cardiovascular mortality is warranted because existing laboratory studies have provided mechanistic evidence of coarse particle effects in this specific domain. For example, prior toxicological research has documented the effects of coarse particle exposure on clinical measures connected to poor cardiovascular outcomes. Yeatts *et al*[26] and Lipsett *et al*[27] demonstrated significant decreases in heart rate variability in panel studies of asthmatics and persons with coronary heart disease, respectively. Such decrements imply compromised control of cardiac autonomic functions that would increase the likelihood of heart attack and death. Coarse particles have also been shown to affect inflammatory processes, such as inducing cytokine release both in vitro and in animal models.[5–7 28–30] A study exposing concentrated ambient coarse particles to a panel of healthy human subjects also suggested increased clotting related to exposure, in addition to the aforementioned inflammatory and autonomic effects.[31] This combination of physiological and biochemical responses may lead to potentially fatal myocardial infarctions, strokes, and arrhythmias.[32]

Previous epidemiological studies have observed impacts on cardiovascular mortality as well, and include Villeneuve *et al*,[33] which found an effect specifically for cardiovascular mortality in Vancouver, Canada, and Ostro *et al*,[23] which reported a doubling of magnitude of cardiovascular effects in the arid Coachella Valley, California when compared to all-cause effects. Conversely, Kan *et al*[14] and Schwartz *et al*[11] did not observe significant associations between coarse particle levels and cardiovascular and ischaemic mortality, respectively.

The relationship between coarse particles and morbidity has also been investigated previously. Studies in Toronto, Canada found statistically significant increases in summertime cardiac admissions and year-round ischaemic heart disease and heart failure admissions associated with increases in coarse particle concentrations.[34 35] In France, Host *et al*[1] found associations between coarse particles and hospitalisations for ischaemic conditions, but only among the elderly. In a study spanning the continental USA, Peng *et al*[2] found associations between $PM_{10-2.5}$ and emergency hospital admissions for cardiovascular disease among Medicare recipients aged ⩾65 years, though these effects were attenuated to non-significance once adjustment for $PM_{2.5}$ was made in their model. They also did not observe any associations when looking specifically at the Western USA. It is possible that robust associations were not observed, in part, because exposure was assigned at the county level. Peng *et al*,[2] as well as a review by Monn,[9] found that coarse particle measures tend to be less spatially homogeneous than fine particles in urban areas. Moreover, counties in the Western USA, on average, encompass greater areas than in the East, increasing the likelihood that county-level measures in the West may not adequately describe the exposure experience for county residents, especially if monitor coverage for a county is sparse. In contrast to the Peng study, which addressed issues with spatial heterogeneity statistically through regression calibration, our analyses addressed the problem more directly by limiting our study to cases that resided within a relatively short distance from the monitor, instead of assigning exposure at the county level. To explore additional possible impacts of exposure misclassification, we compared analyses using a 10 km buffer to our initial 20 km buffer analysis. The differences between the two sets of analysis were fairly modest.

In our study, we also investigated effects of coarse particles on cardiovascular mortality after adjustment for fine particles. Such adjustment decreased precision, but the vast majority of significant findings remained so after adjustment. This lack of impact of $PM_{2.5}$ adjustment is likely due to its low correlation with coarse particles in our study counties. This finding provides some reassurance that our findings were more likely a result of an independent coarse particle exposure, and not due to confounding with fine particle levels. This contrasts with other studies adjusting for fine particles, which generally reported attenuation of coarse particle results to non-significance.[2 13 34] Because some overlap exists in the size ranges between mechanically generated particles that generally fall

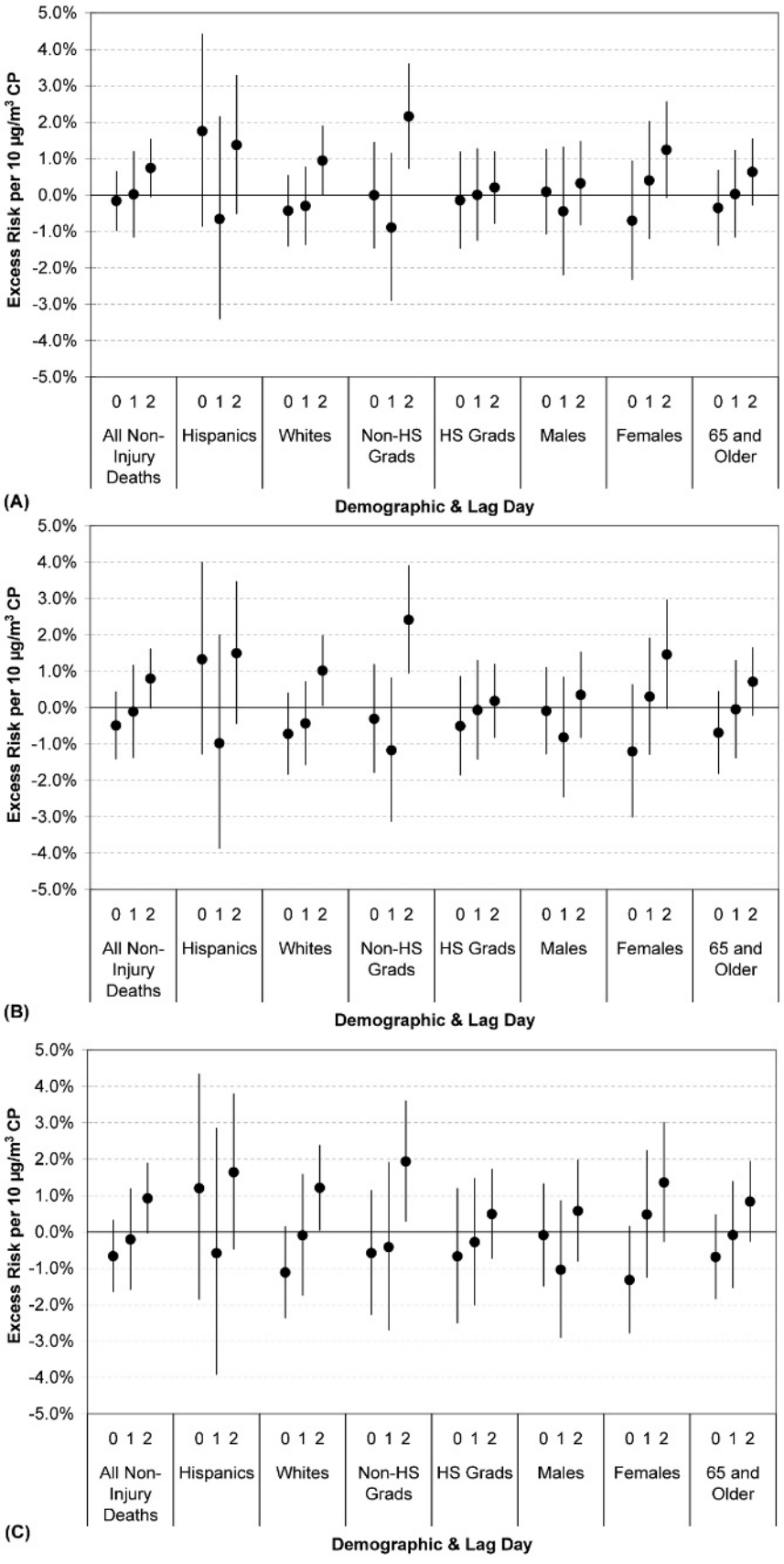

Figure 2 Excess risks (and 95% CI) of non-injury mortality per 10 μg/m³ increase in coarse particles, by demographic and number of days' lag between exposure and death (A) for those within 20 km of a coarse monitoring site; (B) those within 20 km, adjusted for fine particles; and (C) those within 10 km. Models adjusted for a 1-day lag of temperature and relative humidity, and for day of week. CP, coarse particles; HS, high school.

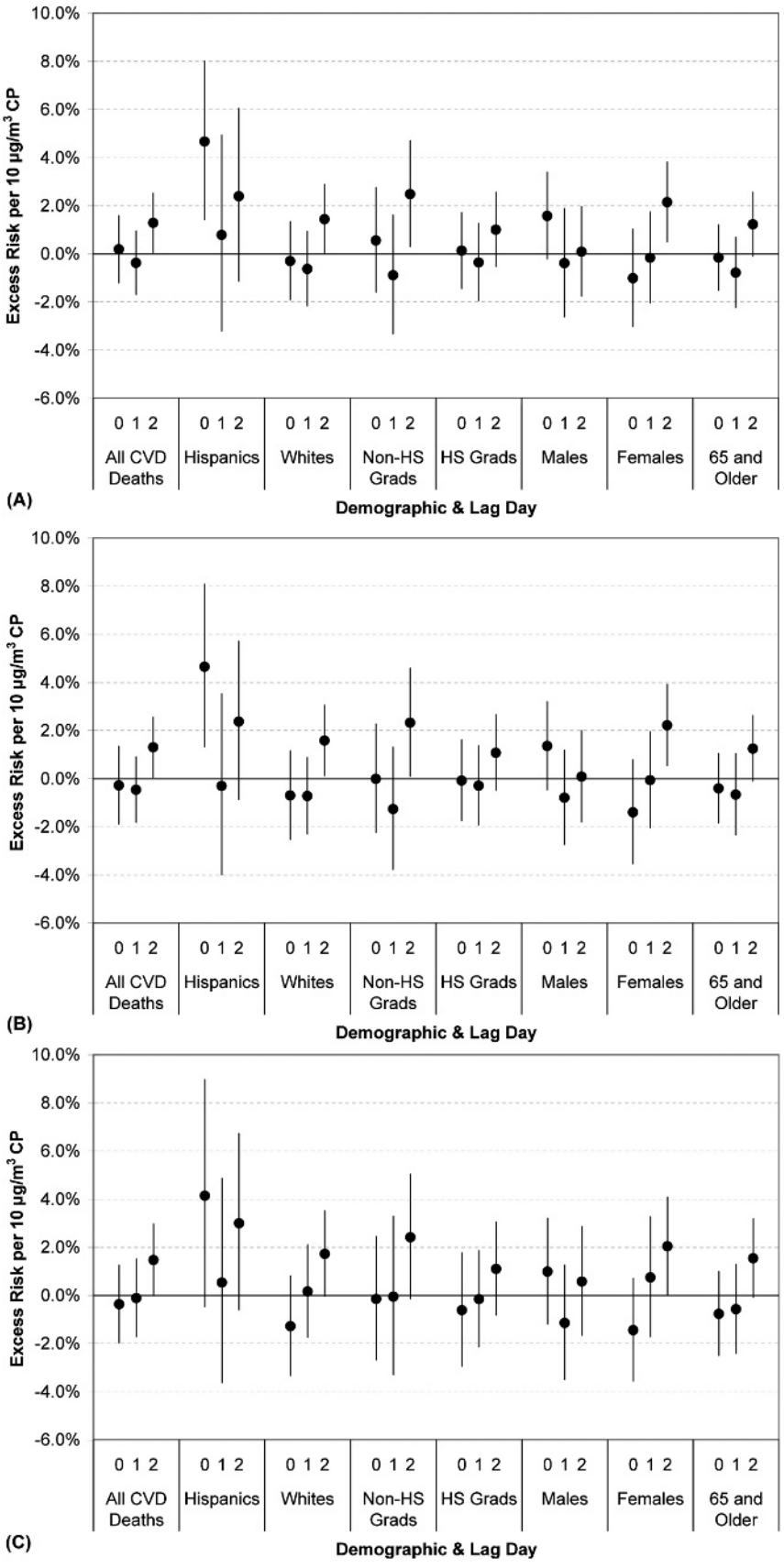

Figure 3 Excess risks (and 95% CI) of cardiovascular mortality per 10 μg/m^3 increase in coarse particles, by demographic and number of days' lag between exposure and death (A) for those within 20 km of a coarse monitoring site; (B) those within 20 km, adjusted for fine particles; and (C) those within 10 km. Models adjusted for a 1-day lag of temperature and relative humidity, and for day of week. CP, coarse particles; CVD, cardiovascular disease; HS, high school.

into the coarse range and combustion-generated fine particles, there is some possibility that the effects detected could be related to fine particles in this intermodal range.

An additional contribution of this study is the finding that risk for cardiovascular mortality associated with coarse particle exposure seemed to be modified by race/ethnicity and educational attainment, both markers of SES. Illustrating this point is the fact that, in 1999, the rate of people below the poverty line for Hispanics was almost three times the rate for non-Hispanic Whites in California.[36] Educational attainment is also a strong predictor of earnings nationwide.[37] The findings of higher risks among Hispanics and those without a high school-level education may be due to chance and need to be confirmed in future research. However, seeing greater effects in these groups mirrors our previous research examining fine particle effects on mortality in the same demographic groups.[18] In contrast, Villeneuve *et al*[33] examined effects of coarse particles on mortality but did not report any differences in findings by SES group. Wilson *et al*[19] found a slightly higher 6-day cumulative effect estimate for a more affluent area of Phoenix when compared with a less affluent area when using zip code-level economic data. That study also suggested more immediate effects on mortality for the lower SES population compared with the higher SES population, a trend we also observed when comparing effects in Hispanics to those in Whites.

The observed modification of effect in populations of lower SES could be due to differences in either exposure or susceptibility. Factors that would increase susceptibility to cardiovascular mortality in lower SES populations include increased work and life stress,[38] poorer nutrition,[39 40] reduced physical activity, higher smoking rates, higher rates of cardiovascular risk factors, and reduced access and use of healthcare to control those risk factors and pre-existing conditions.[41–44] Moreover, the significant effects we find for Hispanics using same-day lags of pollution could be due to the fact that people in this subpopulation have limited access to healthcare and could be more reluctant to seek care during the first signs of a serious cardiovascular problem, such as a heart attack.[45]

Differences in exposure levels between those of lower educational attainment and those of more advanced education are also likely. Studies of air and other types of pollution have shown that disadvantaged communities tend to suffer from higher exposures.[46–49] For example, a study of all census block groups in California found that those in the lowest quartile of median family income were three times more likely to have high traffic density compared with those in the highest quartile.[50] Traffic represents an important source of coarse particles in urban areas via resuspended road dust,[51] and the bulk of mass generated from brake wear during urban driving also falls within this size range.[52] Those of lower SES could also be more likely to spend time outdoors, either recreationally or professionally. Indeed, the US Census' American Community Survey for 2000 indicates a higher proportion of Hispanics in California work in occupations classified as construction, extraction or agriculture.[53] Differences in the housing stock between the groups could also exist, allowing greater penetration of coarse particles into low SES households. Residential penetration of particles also depends on central air conditioning usage, and either ownership or usage of central cooling can be dependent on economic status.[54]

There are some limitations in this study that could be addressed in future research. First, the coarse particle levels provided by the California Air Resources Board were generally only available every 6 days. This means that each estimate calculated for a specific lag day is derived from a different risk set than another lag day. For example, lag 0 estimates compare particle levels measured that day with deaths that occurred on measurement days, but lag 1 estimates compare coarse particle levels with deaths that occurred 1 day after these specific measurement days. This means that differences in lag days could be due to random differences between these two risk sets, and adds more uncertainty to any comparisons between lags. It is of note, however, that no significant differences were observed in the proportions of age, sex, ethnicity, or education groups, or by distance to monitor between the different populations. Furthermore, it is likely that cumulative exposure may contribute more heavily to cardiovascular mortality. However, as every day data were not available, we were not able to test this hypothesis. Another issue related to this study's exposure assessment is the fact that coarse particles were not directly measured, but were calculated by taking the difference of collocated PM_{10} and $PM_{2.5}$ measurements. This indirect method of calculation introduces possible measurement error from each of the PM monitors, which may reduce the chances of detecting an association, should one exist. Significant associations that were detected could also be due to a type I error, which is more likely to be reported in an analysis where multiple tests are conducted, though our multi-county design should decrease that likelihood to some extent. The use of a multi-county design does add the possibility that we are combining possibly heterogeneous estimates. However, none of the statistically significant results we reported showed any evidence of heterogeneity ($p>0.20$). Future studies in the area should work to corroborate our findings regarding the susceptibility of certain subgroups.

Another shortcoming of this study is the inability of this study to examine impacts from specific components of the coarse particle fraction. Previous research has suggested that coarse particles with different chemical constitutions can have differing effects.[55–57] Endotoxin, which is mostly contained in the coarse fraction, has been implicated as an important trigger of cytokine production in in vitro and in vivo studies.[5 7 58] However, other studies found that certain metals and crustal minerals are also strongly associated with cell death and inflammatory reactions.[55 56] Further studies are needed to elucidate toxicological differences in coarse particle components and which components pose the greatest health risk.

Using data from 15 counties in California, we found evidence of an association between coarse particles and both all-cause and cardiovascular mortality, particularly among demographic subgroups of lower SES. Our study took advantage of the fact that coarse particle levels and ranges are greater in California, allowing us to more readily detect an association. Our results are strengthened by three design elements of our study. First, we used multiple counties to better protect against a single chance result unduly influencing our findings. Second, we restricted study eligibility to those residing close to the air pollution monitors, thus reducing the amount of exposure misclassification occurring in our analyses. Lastly, we were able to control for fine particles levels, better ensuring that the effects observed were indeed associated specifically with coarse particles and not the result of any correlation between the two fractions.

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