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Triggering of Myocardial Infarction by Increased Ambient Fine Particle Concentration: Effect Modification by Source Direction

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Abstract

Background—Previously, we reported a 18% increased odds of ST-elevation myocardial infarction (STEMI) associated with each 7.1 $\mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ concentration in the hour prior to MI onset. We found no association with non-ST elevation myocardial infarction (NSTEMI). We examined if this association was modified by $\text{PM}_{2.5}$ source direction.

Methods—We used the NOAA HYbrid Single-Particle Lagrangian Trajectory (HYSPLIT) model to calculate each hourly air mass location for the 24 hours before each case or control time period in our previous $\text{PM}_{2.5}$ /STEMI case-crossover analysis. Using these data on patients with STEMI ($n=338$), hourly $\text{PM}_{2.5}$ concentrations, and case-crossover methods, we evaluated whether our $\text{PM}_{2.5}$ /STEMI association was modified by whether the air mass passed through each of the 8 cardinal wind direction sectors in the previous 24 hours.

Results—When the air mass passed through the West-Southwest direction (WSW) any time in the past 24 hours, the odds of STEMI associated with each 7.1 $\mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ concentration in the previous hour ($\text{OR}=1.27$; 95% $\text{CI}=1.08, 1.22$) was statistically significantly ($p=0.01$) greater than the relative odds of STEMI associated with increased $\text{PM}_{2.5}$ concentration when the wind arrived from any other direction ($\text{OR}=0.99$; 95% $\text{CI}=0.80, 1.22$). We found no other effect modification by any other source direction. Further, relative odds estimates were largest when the time spent in the WSW was 8–16 hours, compared to 7 hours or 17–24 hours, suggesting that particles arising from sources in this direction were more potent in triggering STEMI.

Conclusions—Since relative odds estimates were higher when the air mass passed through the WSW octant in the past 24 hours, there may be specific components of the ambient aerosol that are more potent in triggering STEMI. This direction is associated with substantial emissions from coal-fired power plants and other industrial sources of the Ohio River Valley, many of which are undergoing modifications to reduce their emissions.

1. INTRODUCTION

Increased ambient particulate matter (PM) concentrations have previously been associated with an increased risk of myocardial infarction (Rich et al. 2010; Mustafic et al. 2012). Using data on acute coronary syndrome events treated at the Strong Memorial Hospital Cardiac Catheterization Laboratory and ambient air pollution measured in Rochester, New York, Gardner et al. (2014) reported that each $7.1 \mu\text{g}/\text{m}^3$ increase in ambient $\text{PM}_{2.5}$ concentration in the previous 1 hour was associated with an 18% increase in the risk of a ST-elevation myocardial infarction (95% CI = 1%, 38%), but no association with non-ST elevation myocardial infarction (NSTEMI; OR= 0.93; 95% CI= 0.78, 1.09).

Recently, Rich et al. (2013) reported larger relative odds of myocardial infarction associated with increased $\text{PM}_{2.5}$ concentrations when the air pollution mixtures were laden with secondary PM species (sulfate, nitrate, and/or organics). These results suggest that secondary particulate matter that is formed through active, oxidative atmospheric chemistry, may be more important in inducing MIs than primary fine particle aerosol. Air masses coming into an area or region would transport different amounts of secondary species and therefore, there may be relationships between atmospheric transport direction and incidence of PM mediated MI events.

Beginning in about 2008, there have been a number of major changes in large sources in the source regions to the west and southwest of the Rochester. Between 2008 and 2014, the Province of Ontario has phased out most of its fleet of coal-fired power plants including the Nanticoke Thermal Generating Station that had been the largest source of SO_2 in North America (Scientific American, 2013). At the same time, there have been substantial reductions in the emissions from the generating stations in the upper Ohio River Basin, in part as a result of legal action against a major utility in the region (USEPA, 2007) and utilities beginning to make changes in response to the Cross-State Air Pollution Rule (EPA, 2011) that has recently been allowed by the courts to go into effect (US Court, 2014).

In this analysis, we examined whether our previously reported $\text{PM}_{2.5}$ /STEMI risk estimate was modified by where the air mass was in the past 24 hours. Using air parcel back trajectory analysis, samples were grouped based on their likely upwind origins during this 24 hour period. This analysis was performed to determine the extent of reductions in airborne PM that can be attributed to these reductions in upwind emissions, and to evaluate whether fine particles from different upwind origins were associated with cardiovascular health effects in residents of Rochester, New York.

2. METHODS

2.1 Study population and outcome definition

The study population used in our analysis has been described previously (Gardner et al 2014). Briefly, the University of Rochester Medical Center (URMC) Cardiac Catheterization Laboratory stores and maintains a database of all acute coronary syndromes treated, including information on the subject (age, race, sex, residential address, previous co-morbidities and procedures, etc.) and the clinical event (i.e. onset date and time, acute coronary syndrome type, etc.). Acute coronary syndromes, either STEMI, NSTEMI, or unstable angina, were defined using the current American College of Cardiology (ACC)/American Heart Association (AHA) guidelines (O’Gara et al 2013). For STEMI, on the presenting electrocardiogram (EKG), this is defined as ST segment elevation greater than 1 mm in 2 or more contiguous precordial leads, or 2 or more adjacent limb leads, or new or presumed new left bundle branch block in the appropriate clinical setting (angina or angina equivalent) and the appearance of detectable cardiac myocyte biomarkers (indicating myocardial necrosis). For NSTEMI, the diagnosis is made by appearance of detectable cardiac myocyte biomarkers (indicating myocardial necrosis) in the blood of a patient without the requirement of the EKG changes associated with STEMI. Unstable angina was not included since the diagnosis of unstable angina can sometimes be based solely on clinical judgment without objective criteria of cardiac ischemia to support the diagnosis of an acute coronary syndrome.

Onset time (date and hour) was self-reported by each patient (or kin if patient was unable to communicate) upon arrival to the URMC Cardiac Catheterization Laboratory. Only patients that presented to the URMC Cardiac Catheterization Laboratory were included in this study.

From these acute coronary syndrome data, we retained all STEMI and NSTEMI events occurring from January 1, 2007 to December 31, 2010 (N=3889), where symptom onset date and time were available, and those where the patient resided within 15 miles of our pollutant monitoring station in Rochester, New York, resulting in n=338 STEMI and n=339 NSTEMI available for analysis. This study was approved by the University of Rochester Medical Center Research Subjects Review Board.

2.2 Air pollution and meteorology measurements

Pollutant concentration data used in the study were measured at the New York State Department of Environmental Protection site in Rochester, New York, located approximately 1500 m from an interstate highway. PM_{2.5} was measured continuously using a Tapered Element Oscillating Microbalance (TEOM; ThermoFisher, Franklin, MA) for each hour during the study period (January 1, 2007 to December 31, 2010). Hourly temperature and relative humidity data were also measured at the site. These hourly pollutant concentration and weather data were used in all statistical analyses described below.

2.3 Air mass back trajectory estimates

Air mass back trajectories were calculated using the NOAA Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT, version 4.7) model (Draxler and Rolph, 2003). The metrological data set REANALYSIS was used to produce 4 trajectories per day starting at 0:00, 6:00, 12:00, and 18:00 local time with a starting height of 500 m. The choice of starting height is based on prior experience in a variety of Potential Source Contribution Function (PSCF) applications (Cheng et al., 1993a; Cheng et al., 1993b; Fan et al., 1994; Polissar et al., 1999; Polissar et al., 2001; Lupu and Maenhaut, 2002) and represents a reasonable representation of transport in the upper portion of the surface boundary layer. One hour endpoints were estimated for 4 days backward in time, but only the final 24 hours were used in this analysis.

The cardinal direction of any single point in a trajectory was defined by the angle between a line due north from the monitor site, and a line from the air mass location to the monitor site. If that angle was 0-45° then the point was assigned to the NNE; ENE if the angle was 45° to 90°; ESE if greater than 90° to 135°; SSE if greater than 135° to 180°; SSW if greater than 180° to 225°; WSW if greater than 225° to 270°; WNW if greater than 270° to 315°; and NNW if greater than 315° to 360°.

For the analysis, we created 8 variables that indicated the cardinal sectors through which each 24 hour trajectory passed. There are 24 1-hour endpoints in each trajectory and each endpoint was assigned to one of the 8 directional sectors. Then each of the 8 variables was assigned a value of 0 or 1 depending if there were any endpoints that fell into that sector during that time period. For example, the indicator variable for NNE is equal to 1 if at least one endpoint along the trajectory was within the NNE sector. Each day might have indicators for more than one direction equal to 1, so each cardinal direction was analyzed in separate equations. For example, risk of MI associated with air masses originating from the NNE was estimated with an equation that included all case and control days, and the coefficient for the NNE indicator variable estimated the risk associated with NNE compared to all other sectors. We conducted sensitivity analyses, described below, to evaluate if our findings were robust to this sector definition.

2.4 Study design

We used a time-stratified case-crossover design (Levy et al 2001; Maclure et al 1991) which we and others have used in studies of ambient air pollution and myocardial infarction (Rich et al 2010; Sullivan et al 2005; Pope et al 2006; Zanobetti and Schwartz 2005), and that has been deemed the preferred referent selection approach (Janes et al 2005; Mittleman 2005). This design is analogous to a matched case-control study. However, instead of contrasting air pollutant concentrations between a person experiencing an acute coronary syndrome (case) and a person who did not (control), it contrasts pollutant concentrations right before the acute coronary syndrome (case-period) to other periods when the subject did not have an acute coronary syndrome, matched to the case-period by calendar month, weekday, and hour of the day (control periods). Since the case and control periods are within the follow-up time of the same person, non-time varying confounders such as health history and smoking status are controlled by design. Factors that vary between case and control time periods (e.g.

weather variables) are possible confounders that need to be included in our statistical models.

2.5 Statistical analysis

Using a conditional logistic regression model stratified on each acute coronary syndrome (one case and three or four control periods), we regressed STEMI case-control status (i.e., case period = 1, control period = 0) against the mean $PM_{2.5}$ concentration in the 1 hour prior to symptom onset (lag hour 0). Using Akaike's information criterion to select the optimal lag time and functional form (natural spline with 2, 3, or 4 degrees of freedom versus 1 degree of freedom/linear), we also included the mean temperature and mean relative humidity in the previous 3 hours (1 degree of freedom) in the model. To examine whether any increased risk of STEMI associated with increased $PM_{2.5}$ concentration was modified by whether the air mass during the case or control period passed through a specific direction [e.g. north-northwest; NNW] in the past 24 hours, we included indicator variables for the NNW air mass wind direction (NNW=1; NNW=0 if direction = ENE, ESE, SSE, SSW, WSW, WNW, NNW [i.e. All Other Directions]) and an interaction term for the $PM_{2.5}$ concentration and wind direction (e.g. $PM_{2.5} * NNW$) to the model. We then repeated this for the other 7 wind directions. A p-value <0.05 was used to define statistical significance.

Second, we examined whether our analyses were robust to the exclusion of WSW from the "All Other Directions" analyses (i.e. for the NNE analyses 'All Other Directions' redefined to include ENE, ESE, SSE, SSW, WNW, NNW). After redefining the "All Other Directions" for each of the 8 cardinal wind directions, we re-ran the same conditional logistic regression model, including the interaction term, described above.

Third, we conducted a similar analysis to our main analysis, but here categorized each 24 hour period before a case or control period with regard to the number of hours when the wind was out of a specified direction (e.g. 0 of 24 of the past hours were winds out of the WSW, 1-7 hours, 8-16 hours, or 17-24 hours) not just whether any hour in the past 24 hours was from that direction. We then re-ran our model described above in our main analysis, including interaction terms for these 'hour' groups ($PM_{2.5} * HOURS_{1-7} + PM_{2.5} * HOURS_{8-16} + PM_{2.5} * HOURS_{17-24}$).

Last, we examined whether dividing these 8 directions into 16 directions provided any more useful information on whether air mass back trajectories modified the relative odds of STEMI associated with increased $PM_{2.5}$ concentration. For example, we divided the WSW into two directions defining WSW-1 as between 247.5° and 270°, and WSW-2 as from 225° to 247.5°. The conditional logistic regression models with the same interaction term described above were rerun separately for the WSW-1 and WSW-2 directions. SAS version 9.32 (©SAS Institute, Inc. Cary, NC) was used to construct all datasets and conduct descriptive analyses, and R (version 2.15.1; R Foundation for Statistical Computing, Vienna, Austria) to perform all conditional logistic regression analyses.

3. RESULTS

The subject characteristics are described in Table 1. Study subjects were primarily older (52% ≥ 60 years of age), white (87%), male (66%), overweight or obese (75%), smokers (65%). Many subjects had a prior myocardial infarction (22%) and been diagnosed with hypertension (66%), dyslipidemia (59%), and/or diabetes (18%).

The distributions of the hourly PM_{2.5} concentration and meteorological data for the study period (January 2007 to December 2010) are shown in Table 2. In addition, the final column of Table 2 presents the interquartile range for distribution of differences between the case values for a subject and the mean control values for that subject. The distribution of trajectory endpoints is presented in Table 3. The prevailing wind directions were SW to NW with 77% of the air masses coming from directions between 180 and 360°. There were also a number of large PM and PM precursor sources in those directions particularly in the SSW and WSE sectors as shown in Figure 1. Table 3 provides the relative odds of a STEMI associated with each 7.1 µg/m³ increase in PM_{2.5} concentration in the previous hour, stratified by wind direction (e.g. if the winds were out of NNE for at least 1 hour in the past 24 hours, versus if the winds were not out of the NNE at any time in the past 24 hours). When winds were out of the WSW, the relative odds of a STEMI associated with each 7.1 µg/m³ increase in PM_{2.5} concentration in the previous hour (1.27; 95% CI = 1.08, 1.22) was statistically significantly (p=0.01) greater than the relative odds of a STEMI associated with each 7.1 µg/m³ increase in PM_{2.5} concentration in the previous hour when the winds were out of all other directions (0.99; 95% CI = 0.80, 1.22)(Table 3).

None of the other directions showed a statistically significant interaction with the PM-STEMI relationship with all of the p-values ≥ 0.17. The relative odds estimates were lower when the winds were out of the NNE, ENE, SSE, and NNW than when winds were not out of these directions (Table 3). However, these larger relative odds estimates for the “other directions” may just be reflecting the greater relative odds of a STEMI associated with increased PM_{2.5} in the WSW direction. Therefore, we examined whether our results for the NNE, ENE, SSE, and NNW directions presented in Table 3 were robust to the exclusion of WSW from the “All Other Directions” analyses (i.e. for the NNE analyses ‘All Other Directions’ redefined to include ENE, ESE, SSE, SSW, WNW, NNW). When excluding WSW from “All Other Directions”, we no longer observed larger relative odds estimates in the “All Other Directions” group compared to the NNE, ENE, and NNW directions (e.g. Table 3-ENE: OR = 1.01 [95% CI = 0.68, 1.48], other directions: OR = 1.19 [95% CI = 1.02, 1.39]; Table 4-ENE: OR = 1.04 [95% CI = 0.51, 2.07], other directions: OR = 1.02 [95% CI = 0.74, 1.40] . However, although they were not statistically significantly different, the relative odds estimate for the SSE (OR=0.69 ; 95% CI = 0.34, 1.89) was substantially smaller than the relative odds estimate for the other directions (OR=1.15; 95% CI = 0.83, 1.59).. However, none of these relative odds estimates for each direction and its corresponding ‘All Other Directions’ were statistically significantly different (Table 4). Finally, when dividing the WSW into 2 directions, we found increased relative odds estimates for both the WSW-1 (247.5° to 270°; OR=1.14, 95% CI = 0.73, 1.61) and WSW-2 (225° to 247.5°; OR=1.28, 95% CI = 0.90, 1.47).

Next, we estimated the relative odds of a STEMI associated with each $7.1 \mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ concentration in the previous hour, separately for those 24 hour periods with 0 of 24 hours with winds out of the WSW, those 24 hour periods with 1-7 hours with winds out of the WSW, 8-16 hours, and 17-24 hours. As shown in Table 5, the relative odds estimates for the 1-7 hour group, 8-16 hour group, and 17-24 hour group were all greater than 1.0, with the largest being that for the 8-16 hour group ($\text{OR}=2.27$; 95% $\text{CI} = 1.42, 3.63$). This estimate was statistically significantly greater ($p=0.001$) than the relative odds estimate for the 0 hour group (0.94; 95% $\text{CI} = 0.74, 1.19$). Further, odds ratio estimates increased from 0 hours to the 1-7 hour group to the 8-16 hour group, but not 17-24 hours.

4. DISCUSSION

The present study examines whether the previously identified $\text{PM}_{2.5}/\text{MI}$ association (Garner et al., 2014) was modified by PM source direction. We observed an increased risk of ST-elevation MI associated with each $7.1 \mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ concentration in the previous hour only when the winds had passed through the directional sector WSW of Rochester. This result appeared independent of the number of hours in which the air mass resided in the WSW, and was not limited to either the northern or southern half of this sector. These results support our previous study that reported a greater risk of myocardial infarction associated with increased $\text{PM}_{2.5}$ concentration in the previous 24 hours for those days when the mass fraction of sulfate, nitrate, and ammonium was in the highest 33%, and when the mass fraction of elemental carbon was in the lowest 33%. Thus the risk of myocardial infarction associated with increased $\text{PM}_{2.5}$ concentration appeared greatest when the air pollution mixture was laden with secondary PM species (Rich et al 2013). However, we can further refine those conclusions based on the present work. Within the SSW section are Pittsburgh and a number of coal-fired power plants. In the WSW sector, there are the major cities of Detroit, Cleveland, and Buffalo and additional coal-fired power plants including the Nanticoke Thermal Generating Station, which was the largest single source of SO_2 in North America until 2009 when its emissions were reduced by 50%. The WNW sector might also have been anticipated to have an effect given that it includes the high population and industrial areas along the western shore of Lake Ontario and the northern half of the Niagara peninsula. However, this direction clearly did not modify our $\text{PM}_{2.5}/\text{MI}$ association.

Aging of the aerosol may also influence and/or modify on the effectiveness of the $\text{PM}_{2.5}$ to induce a STEMI. When the air mass was in the WSW sector for 1-7 hours in the WSW, the OR was little different from the OR for 1 hour in the WSW results as shown in Table 5. However, when the air parcels remained in the WSW sector for 8-16 hours, the OR increased to 2.27 with a 95% confidence interval from 1.42 to 3.63. Then, when the air remains longer in the sector, 17-24 hours, the OR drops to 1.20 with a 95% confidence interval of 0.91 to 1.58. Longer residence times in the sector likely resulted in more aging of the particles that would result in more oxidized and lower volatility secondary organic species (Donahue et al. 2012; Ehn et al 2014). Thus, some aging would seem to raise their toxicity since atmospheric oxidation can result in the formation of peroxides and peroxy radicals (Hopke, 2015). However, too much aging likely reduced their activity through conversion of the peroxy species to carbonyls that have little to no influence on MI

induction. The nature of these chemical changes is not yet understood, and is beyond the scope of our present study.

When we tried to refine the locations of the source material for the particles, we reduced the number of events in each of the two subsectors, WSW-1 and WSW-2, such that the OR values in each subsector are of similar size. Although we observed an increased risk of STEMI associated with increased $PM_{2.5}$ when the air mass passed through either direction, we cannot provide more detailed localization of the likely important source areas without data on more subjects.

There are several limitations that should be noted when making conclusions on these results. As discussed previously, the STEMI symptom onset time was self-reported by the patient or kin if the patient was unable to communicate (Gardner et al, 2014). Therefore, it is possible that the air masses associated with that reported onset time (i.e. air masses in the 24 hours before symptom onset time) may be mismatched by one or more hours. However, it is reasonable to assume that this reporting error would be uncorrelated with wind direction (i.e. WSW versus not WSW). Therefore, each odds ratio estimate (e.g. WSW OR=1.27; not WSW OR = 0.99) is likely an underestimate of its true odds ratio. However, there should be minimal impact on the conclusion that we observed an increased risk of STEMI associated with increased $PM_{2.5}$ concentration in the previous hour only when the winds had passed through the directional sector WSW of Rochester in the past 24 hours. Also, we used ambient $PM_{2.5}$ concentrations measured at one monitoring location in Rochester, to represent each patient's exposure to $PM_{2.5}$ of outdoor origin, regardless of how close subjects lived to the monitoring site. This exposure error, however, is not likely different for time periods immediately preceding the STEMI and other time periods in the weeks before or after the STEMI. Thus, this also likely resulted in biases toward the null and underestimates of risk. Last, we also had limited sample size due to our use of existing STEMI data, the requirement of symptom onset time data, and a residence within 15 miles of the monitoring site. This resulted in reduced statistical power and limited precision in our risk estimates.

5. CONCLUSIONS

These results support the conclusion of Rich et al. (2013) which reported that mixtures laden with secondary components of $PM_{2.5}$ may more readily trigger myocardial infarctions than mixtures with lesser proportions of such secondary particles. Winds coming to Rochester from the WSW may contain more secondary particles than other directions, but confirmatory work is needed. Further, the age of the secondary material appears to have an impact on its ability to trigger acute myocardial infarctions, in that air spending 8 to 16 hours in the WSW sector had relative odds that were twice those for air spending 1 hour in this sector. These results suggest the need for further study of the influence of secondary particle formation on the rate of STEMI events and the potential for deactivation of material over time. These and similar data could have potentially important regulatory impacts. For example, our results suggest that this analytic framework could be used to later assess whether the electricity policy changes in Ontario and other locations upwind of Rochester, NY may beneficially impact the cardiovascular health of western New York (i.e. Rochester

area) residents. This could certainly be the case in other sites in New York, as well as communities across the country.

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Figure 1. Eastern United States showing locations of the electric power generating stations and the WSW sector. Dotted line separates the WSW sector into WSW1 (top) and WSW2 (bottom).

Table 1

Patient characteristics.

Characteristic	STEMI (n=338)	
	N	%
Age		
<50 years	58	17%
50–59 years	106	31%
60–69 years	92	27%
70–79 years	46	14%
80 years	34	10%
Missing age	2	1%
Male	224	66%
Race		
White	207*	87%
Black	27	11%
Other	4	2%
Clinical presentation (may have more than 1)		
Study subjects with data on ACS presentation	241	71%*
Prior myocardial infarction	54	22%
Prior Percutaneous Coronary Intervention	45	19%
Prior Coronary Artery Bypass Surgery	10	4%
CVD (“Stroke” in 07–08, “CVD” in 09–10)	12	5%
Peripheral Arterial Disease	16	7%
Smoking	156	65%
Hypertension	160	66%
Dyslipidemia	143	59%
Diabetes	44	18%
Prior Heart Failure	6	2%
Body Mass Index (BMI)		
Overweight (25 kg/m ² ≤ BMI < 30 kg/m ²)	99	41%
Obesity (BMI ≥ 30 kg/m ²)	52	22%
Severe Obesity (BMI ≥ 35 kg/m ²)	28	12%
Mean ± STD	28±5	
Left Ventricular Ejection Fraction		
35%	48	20%
45%	98	41%
Mean ± Standard Deviation	43±14	

* STEMI: Total n=238 with race/ethnicity information. There were n=100 (30% of n=338) with missing race/ethnicity

Distribution of hourly pollutant concentrations and weather characteristics during the study period (Jan 1, 2007–Dec. 31 2010). N=1461 possible days.

Table 2

Pollutant/ Weather Variable	N	Mean	STD	Min	25 th	50 th	75 th	Max	Case- control	
									IQR	IQR
PM _{2.5} (µg/m ³)	1283	8.00	5.70	0.27	3.9	6.7	10.2	43.0	6.3	5.3
Temperature (°C)	1460	10	10	-13	2	11	20	30	18	5
Relative Humidity (%)	1461	65	12	30	57	66	74	94	17	11

Relative odds of STEMI (n=338) associated with each $7.1 \mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ concentration in the previous hour, by wind direction in the past 24 hours. Statistically significant results ($p < 0.05$) are in bold.

Table 3

Direction	% of case/control periods with air mass passing through this direction	WHEN WIND FROM THIS DIRECTION IN PAST 24 HOURS		WHEN WIND FROM ALL OTHER DIRECTIONS IN PAST 24 HOURS		
		Odds Ratio	95% confidence interval	Odds Ratio	95% confidence interval	Interaction term p-value
NNE	9%	0.98	0.66, 1.50	1.19	1.02, 1.39	0.34
ENE	5%	1.01	0.68, 1.48	1.19	1.02, 1.39	0.40
ESE	4%	1.14	0.77, 1.51	1.18	1.01, 1.38	0.84
SSE	4%	0.98	0.71, 1.38	1.20	1.02, 1.40	0.20
SSW	11%	1.12	0.93, 1.22	1.23	1.03, 1.47	0.32
WSW	22%	1.27	1.08, 1.22	0.99	0.80, 1.22	0.01
WNW	22%	1.23	0.99, 1.28	1.17	1.00, 1.37	0.61
NNW	22%	1.03	0.73, 1.42	1.19	1.01, 1.39	0.38

Relative odds of STEMI (n=338) associated with each 7.1 $\mu\text{g}/\text{m}^3$ increase in the mean $\text{PM}_{2.5}$ concentration in the previous hour, by wind direction in the past 24 hours. 'All other directions' excludes WSW. Statistically significant results ($p < 0.05$) are in bold.

Table 4

Direction	WHEN WIND FROM THIS DIRECTION IN PAST 24 HOURS		WHEN WIND FROM ALL OTHER DIRECTIONS IN PAST 24 HOURS		Interaction term p-value	
	Odds Ratio	95% confidence interval	Odds Ratio	95% confidence interval		
NNE	1.14	0.49, 2.37	1.03	0.75, 1.41		0.82
ENE	1.04	0.51, 2.07	1.02	0.74, 1.40		0.96
ESE	1.43	0.66, 2.26	0.98	0.71, 1.35		0.37
SSE	0.69	0.34, 1.89	1.15	0.83, 1.59		0.17
SSW	0.84	0.53, 1.56	1.15	0.79, 1.68		0.30
WSW	1.37	1.11, 1.29	0.92	0.73, 1.17		0.01
WNW	1.21	0.67, 1.85	0.98	0.71, 1.36		0.53
NNW	1.13	0.65, 1.77	0.95	0.67, 1.34		0.59

Relative odds of ST-elevation myocardial infarction (STEMI) associated with each 7.1 µg/m³ increase in ambient fine particle concentration, stratified by hours air mass spent in WSW, before case/referent period. Statistically significant results (p<0.05) are in bold.

Table 5

	n case periods	n control periods	OR	95% CI	p-value for interaction
Main analysis (no interaction with WSW)	338	1174	1.18	1.01, 1.38	---
Effect Modification by WSW defined as >= 1 hour in WSW					
WSW	141	420	1.27	1.08, 1.50	0.01
Not WSW	197	754	0.99	0.80, 1.22	
Effect Modification by WSW defined by number of hours in WSW					
WSW for 1–7 hours	29	105	1.04	0.63, 1.74	0.70*
WSW for 8–16 hours	42	106	2.27	1.42, 3.63	0.001*
WSW for 17–24 hours	70	209	1.20	0.91, 1.58	0.17*
Not WSW (WSW for 0 hours)	197	754	0.94	0.74, 1.19	---

* Tests whether the log odds ratio for this group (e.g. 'WSW for 1–7 hours', 'WSW for 8–16 hours', 'WSW for 17–24 hours') is statistically significantly different from the log odds ratio for the 'WSW for 0 hours' group