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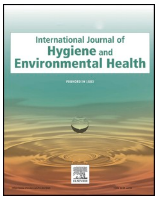

Short-term effects of ambient particulate matter (PM_1, $PM_{2.5}$ and PM_{10}) on influenza-like illness in Guangzhou, China

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ABSTRACT

Background: Particulate matter (PM) has been linked to respiratory infections in a growing body of evidence. Studies on the relationship between ILI (influenza-like illness) and PM_1 (particulate matter with aerodynamic diameter ≤ 1 μm) are, however, scarce. The purpose of this study was to investigate the effects of PM on ILI in Guangzhou, China.

Methods: Daily ILI cases, air pollution records (PM_1, $PM_{2.5}$, PM_{10} and gaseous pollutants), and metrological data between 2014 and 2019 were gathered from Guangzhou, China. To estimate the risk of ILI linked with exposure to PM pollutants, a quasi-Poisson regression was used. Additionally, subgroup analyses stratified by gender, age and season were carried out.

Results: For each 10 $\mu g/m^3$ increase of PM_1 and $PM_{2.5}$ over the past two days (lag01), and PM_{10} over the past three days (lag02), the relative risks (RR) of ILI were 1.079 (95% confidence interval [CI]: 1.050, 1.109), 1.044 (95% CI: 1.027, 1.062) and 1.046 (95% CI: 1.032, 1.059), respectively. The estimated risks for men and women were substantially similar. The effects of PM pollutants between male and female were basically equivalent. People aged 15–24 years old were more susceptive to PM pollutants.

Conclusions: It implies that PM_1, $PM_{2.5}$ and PM_{10} are all risk factors for ILI, the health impacts of PM pollutants vary by particle size. Reducing the concentration of PM_1 needs to be considered when generating a strategy to prevent ILI.

1. Introduction

Ambient air pollution, particularly particulate matter (PM), has grown to be one of the biggest threats for worldwide public health. Globally, 2.94 million deaths from all causes and 83 million disability-adjusted life-years (DALYs) were attributable to ambient particle mass with an aerodynamic diameter less than 2.5 μm ($PM_{2.5}$) in 2017 (Lancet, 2018). Numerous epidemiological studies have demonstrated a link between PM exposure and an increased risk of mortality and morbidity, such as cardiovascular diseases and respiratory diseases (Chen et al., 2017; Hu et al., 2018; Lin et al., 2018; Lin et al., 2016a,b; Shah et al., 2015). With 1.24 million deaths and 1513.1 per 100,000 age-standardised DALY rate estimated to be attributed to air pollution in 2017 (Yin et al., 2020), China is suffering greatly from disease and economic burdens brought on by ambient air pollution. Around 310 billion yuan in losses were caused by air pollution in China (Niu et al., 2017).

A variety of particle size fractions, including PM_{10} (inhalable particles, < 10 μm), $PM_{2.5}$ (fine particles, < 2.5 μm) and PM_1 (very fine particles, < 1 μm) were associated with respiratory mortality and respiratory diseases (Liu et al., 2019; Wang et al., 2021; Zhang et al., 2020; Zhao et al., 2017). PM can induce airway epithelial cell damage and

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barrier dysfunction, and inhibit the defense systems of the respiratory system (Ciencewicki and Jaspers, 2007). Additionally, there is a positive association between $PM_{2.5}/PM_{10}$ exposure and influenza-like illness (ILI) (Chen et al., 2017; Huang et al., 2016; Liu et al., 2019; Su et al., 2019; Toczylowski et al., 2021). ILI is a common respiratory syndrome that has a big impact on public health and causes a significant amount of morbidity and mortality annually (Paget et al., 2019).

According to recent studies, smaller PM particles may be more toxic to humans (Wang et al., 2021; Yang et al., 2019). In China, PM_1 makes up around 80% of the $PM_{2.5}$ mass (Chen et al., 2018). However, due to the absence of ground-based PM_1 measurement, only a small number of research have concentrated on the relationship between PM_1 and health. Besides that, there is presently no research on how PM_1 may affect ILI. In this study, we aimed to investigate the short-term effects of ambient PM_1, $PM_{2.5}$ and PM_{10} on the incidence of ILI in a megacity in southern China.

2. Materials and methods

2.1. Study settings

The capital of Guangdong Province, which is Guangzhou City is important as the economic hub of South China's Peral River Delta Region. Along with the rapid economic development, the concentration of air pollutants in Guangzhou exceeds the standards set by the World Health Organization (WHO). Furthermore, Guangzhou has a subtropical humid-monsoon climate, the seasonal pattern of ILI in Guangzhou was typical of Southern China: with a bimodal increase in both the summer and winter (Shu et al., 2010).

2.2. Data collection

2.2.1. Data of ILI cases

Data of daily ILI cases from January 1, 2014 to December 31, 2019 were collected from Guangzhou Center for Disease Control and Prevention. Herein, ILI cases were defined as an acute respiratory infection with a body temperature higher than 38 °C, and cough or sore throat without other diagnoses. Influenza is a Class-C notifiable infectious disease in China, therefore, sentinel hospitals are obligated to collect a nasopharyngeal swab from each case, transmit it to certified laboratories for viral isolation and subsequent identification, and submit the results online within 24 h. The ILI cases were classified into five age groups: 0–4, 5–14, 15–24, 25–59 and ≥60 years old.

2.2.2. Air pollution data

With a spatial resolution of 10 km × 10 km, the ChinaHighAirPollutants (CHAP, available at https://weijing-rs.github.io/product.html) grid dataset provided us with the daily average concentrations of PM (PM_1, $PM_{2.5}$, PM_{10}) (Wei et al., 2019, 2021a,b) and gaseous pollutants (NO_2: nitrogen dioxide, SO_2: sulfur dioxide, O_3: ozone) (Wei et al., 2022a,b,c) in Guangzhou. Herein, the CHAP dataset presented here is a comprehensive, high-resolution, long-term, and high-quality dataset of ground-level air pollutants for China. Moreover, it is generated using artificial intelligence by considering the spatiotemporal heterogeneity of air pollution based on big data from sources such ground observations, satellite remote sensing products, atmospheric reanalysis and model simulations. With the determination coefficient R^2 between 0.74 and 0.77, the cross-validation results showed that the model maintained a high level of prediction accuracy.

2.2.3. Meteorological data

The China Meteorological Data Sharing Service system of the China Meteorological Administration was used to acquire daily meteorological data, including mean temperature and relative humidity, over the study period (http://data.cma.cn).

2.3. Statistical analysis

Herein, descriptive analysis was performed to uncover the distributions of ILI cases, air pollutants and meteorological data. Meanwhile, the association between each air pollutant and meteorological covariates was estimated using the Spearman correlation.

A generalized additive model (GAM) with a quasi-Poisson regression was used to assess the association between daily PM pollutants and ILI cases. In order to account for seasonality, we also utilized a natural cubic spline with 7 degrees of freedom. To control for the short-term trend, the day of the week (DOW), a categorical variable, was employed. Moreover, we used a natural cubic spline with 3 degrees of freedom to control for the confounding effects of meteorological variables (mean temperature and relative humidity).

The model used is shown as follows:

$$\log[E(\mathrm{Y_t})] = \beta X_i + \mathrm{ns}\ (\mathrm{time},\ \mathrm{df} = 7/\mathrm{year}) + \mathrm{ns}\ (\mathrm{temperature},\ \mathrm{df} = 3) + \mathrm{ns}\ (\mathrm{relative\ humidity},\ \mathrm{df} = 3) + \mathrm{DOW} + \mathrm{intercept} \tag{1}$$

where $E(\mathrm{Y_t})$ represents the expected value of the daily count of ILI cases; ns () is the smoothing function and df is the degree of freedom; β is the regression coefficient for each air pollutant; X_i is the air pollutants such as PM_1, $PM_{2.5}$, PM_{10}; and DOW indicates the day of the week.

According to previous studies (Huang et al., 2016; Chen et al., 2017), PM-ILI associations were significant during lags of 0–3 days. And a systematic review (Lessler et al., 2009) revealed that the incubation period for most ILI-associated acute respiratory infections is within 4 days. Therefore, the models with single-day lag (lag0–lag4) and moving average lag (lag01–lag04) were fitted to comprehend the characteristics of the possible lag effect between PM concentration and the onset of ILI cases.

Furthermore, we conducted several subgroup analyses stratified by gender (male and female) and age group (0–4, 5–14, 15–24, 25–59 and ≥ 60 years old) on the lag day with the strongest effects. In addition, the study period was further separated into warm (from April to September) and cold (October to March of the following year) seasons to determine the seasonal pattern of PM-ILI associations (Liu et al., 2019; Zhang et al., 2020). Then, between-group significance tests were carried out using the formula $(Q_1 - Q_2) \pm 1.96\sqrt{SE_1^2 + SE_2^2}$, where Q_1, Q_2 stood for the effect estimates for each stratum, and SE_1, SE_2 represented the related standard errors (Lin et al., 2016a; Zhang and Zhou, 2020).

Meanwhile, in sensitivity analysis, to check whether the PM-ILI associations would be modified by other air pollutants, we constructed two-pollutant models by adjusting for gaseous air pollutants (NO_2, SO_2 and O_3). By altering the df of time (from 6 to 10) and meteorological variables (from 3 to 6), we examined the potential influence of df. Considering the comparability of PMs concentration changes, we also estimated the effects of PMs on ILI with an interquartile range (IQR) increase.

The attributable number (AN) of ILI cases caused by PM and corresponding attributable fractions (AF) of ILI cases were calculated using previously published methodologies to determine the burden of ILI cases attributable to PM (Qiu et al., 2019; Wu et al., 2020). Based on the WHO's air quality recommendations, we established the reference PM values as 50 $\mu g/m^3$ for PM_{10}, and 25 $\mu g/m^3$ for $PM_{2.5}$. Considering that the current WHO pollution criteria lack pertinent information on PM_1, we used the 50th quantiles of observed PM_1 concentrations as the reference concentration for PM_1. The formula are as follows:

$$AF_i = 1 - \exp\left(-\beta * \Delta P_i\right) \tag{2}$$

$$AN_i = AF_i * n_i \tag{3}$$

where AF_i and AN_i represent the fractions and number of ILI cases, that might be attributed to excessive PM exposures on day i, respectively; β indicates the coefficient of the PM-ILI associations; ΔP_i is the difference in PM concentration between the measured value and the reference

Table 1
Descriptive statistics for meteorological data, air pollutants and influenza-like illness cases in Guangzhou, 2014–2019.

Variable	Mean ± SD	Percentile				
		Min	P_{25}	P_{50}	P_{75}	Max
Temperature (°C)	22.29 ± 5.99	3.46	17.83	23.55	27.41	31.44
Relative humidity (%)	79.16 ± 10.66	26.88	73.63	80.38	86.81	99.75
Air pollution(μg/m^3)						
PM_1	20.92 ± 10.91	2.97	12.93	18.17	26.99	83.69
$PM_{2.5}$	34.79 ± 17.05	6.10	22.19	30.99	44.23	132.60
PM_{10}	54.45 ± 22.53	12.09	37.88	49.5	67.65	160.45
NO_2	33.90 ± 10.73	9.27	26.47	31.23	39.38	81.55
SO_2	13.42 ± 5.49	5.13	9.60	12.16	15.87	40.19
O_3	94.85 ± 41.73	11.78	62.35	90.75	123.06	228.04
Influenza cases and subgroups						
All cases	101.47 ± 246.31	0	7	24	77	2985
Male	55.34 ± 135.11	0	4	13	42	1627
Female	46.13 ± 111.46	0	3	11	34	1358
0–4 years old	35.57 ± 70.62	0	3	10	30	642
5–14 years old	40.62 ± 133.56	0	1	6	26	1735
15–24 years old	8.28 ± 25.86	0	0	1	5	329
25–59 years old	13.94 ± 30.37	0	1	3	11	249
60 years old and above	3.06 ± 5.74	0	0	1	3	50
Warm	74.99 ± 137.93	0	9	27	54	909
Cold	128.06 ± 318.03	0	5	19	108	2985

value on day i; and n_i is the count of ILI cases on day i. Meanwhile, the sum of AN was divided by the total number of ILI cases to determine the overall AF.

All analyses were completed in R software version 4.1.1. Two-sided statistical tests were conducted, and statistical significance was defined as $p < 0.05$.

3. Results

The mean daily concentrations of PM_1, $PM_{2.5}$ and PM_{10} were 20.92, 34.79 and 54.45 μg/m^3, respectively (Table 1). Herein, the daily average concentrations of both $PM_{2.5}$ and PM_{10} exceeded the WHO's air quality guidelines ($PM_{2.5}$: 25 μg/m^3; PM_{10}: 50 μg/m^3). During the study period, the average values were 22.29 °C and 79.16% for mean temperature and relative humidity, respectively. A total of 222,316 ILI cases were recorded, with a daily mean of 101.47. Among all age groups, cases aged 5–14 years old accounted for 40.03% of the total ILI cases.

Table 2 demonstrates the correlation between air pollutants and meteorological variables. Herein, strong correlations were observed between PM_1 and $PM_{2.5}$ ($r = 0.99$, $p < 0.001$), $PM_{2.5}$ and PM_{10} ($r = 0.98$, $p < 0.001$), and PM_1 and PM_{10} ($r = 0.96$, $p < 0.001$). PM_1, $PM_{2.5}$ and PM_{10} were positively correlated with NO_2, SO_2 and O_3, whilst were negatively correlated with mean temperature and relative humidity.

Fig. 1 shows the relative risk (RR) for daily ILI cases at different lag days associated with per 10 μg/m^3 increase exposure to PM pollutants. For a single-day lag, PM_1 and $PM_{2.5}$ had a significant effect on ILI cases on lag0–lag2, whilst PM_{10} had a significant effect on lag0–lag3. Herein, the risks related to PM exhibited a declining tendency as the lag day grew. Meanwhile, for multi-day lag, the effects of all PM pollutants on ILI cases were significant on lag01–04. Herein, the effects of PM_1 were stronger than that of $PM_{2.5}$ and PM_{10}. The strongest effects of PM_1 and $PM_{2.5}$ were observed at the two-day moving average (lag01), with corresponding RR 1.079 (95% confidence interval [CI]: 1.050, 1.109) for PM_1 and 1.044 (95% CI: 1.027, 1.062) for $PM_{2.5}$, respectively (Table S1). Meanwhile, the strongest effect of PM_{10} was observed at a three-day moving average (lag02), the RR was 1.046 (95% CI: 1.032, 1.059).

In addition, subgroup-specific RR estimates for the associations between PM pollutants and ILI cases with the strongest effect were summarised in Fig. 2. Subgroup results stratified by gender and age group were similar between the 3 p.m. pollutants. Herein, the risks estimated between males and females were substantially similar. For instance, the RR was 1.075 (95% CI: 1.044, 1.105) among males and 1.085 (95% CI: 1.054, 1.117) among females, with a 10 μg/m^3 increase in exposure to PM_1 (Table S2). Although the differences are not significant except for PM_{10}, the age-stratified analysis revealed that the 15–24-year group may be more sensitive to PM pollutants.

Moreover, PM_1-and $PM_{2.5}$-ILI associations were slightly stronger in the warm season than in the cold seasons for total ILI cases, whereas the PM_{10}-ILI association was stronger in cold seasons (Fig. 3, Table S3). Meanwhile, the stratified analysis showed that the PM-ILI associations among males (except for PM_{10}) and the 5–14 age group were stronger in warm seasons, whilst other results were stronger in cold seasons.

Table 3 shows the attributable number and attributable fractions of ILI cases related to PM pollutants. Herein, the attributable fractions of total ILI cases were estimated to be 1.43% (95% CI: 0.88, 1.93) due to PM_1, 2.48% (95% CI: 1.44, 3.50) due to $PM_{2.5}$, and 2.33% (95% CI: 1.97, 2.68) due to PM_{10}. During the study period, 3190 (95% CI: 1934, 4319) ILI cases were estimated to be attributable to PM_1, whereas 5510 (95% CI: 3319, 7692) ILI cases were attributable to $PM_{2.5}$ and 5176 (95% CI: 4346, 6001) ILI cases were attributable to PM_{10}.

The results from the two-pollutant models illustrated that the estimated effects decreased after adding NO_2 and SO_2 to the models (Table S4). With the exception of PM_{10}, the impacts of PM_1 and $PM_{2.5}$ were no longer significant when the aforementioned pollutants were included. On the contrary, the PM-ILI associations increased after adjusting for O_3, and the results remained significant. Meanwhile, sensitivity analyses showed that our main findings were robust when

Table 2
Spearman correlation coefficients between air pollutants and meteorological variables in Guangzhou, 2014–2019.

	PM_1	$PM_{2.5}$	PM_{10}	NO_2	SO_2	O_3	Temperature	Relative humidity
PM_1	1.00							
$PM_{2.5}$	0.99**	1.00						
PM_{10}	0.96**	0.98**	1.00					
NO_2	0.70**	0.69**	0.71**	1.00				
SO_2	0.66**	0.68**	0.68**	0.41**	1.00			
O_3	0.29**	0.34**	0.42**	0.08**	0.25**	1.00		
Temperature	−0.42**	−0.34**	−0.27**	−0.38**	−0.11**	0.42**	1.00	
Relative humidity	−0.40**	−0.39**	−0.44**	0.01	−0.40**	−0.52**	0.15**	1.00

Note: **$p < 0.001$.

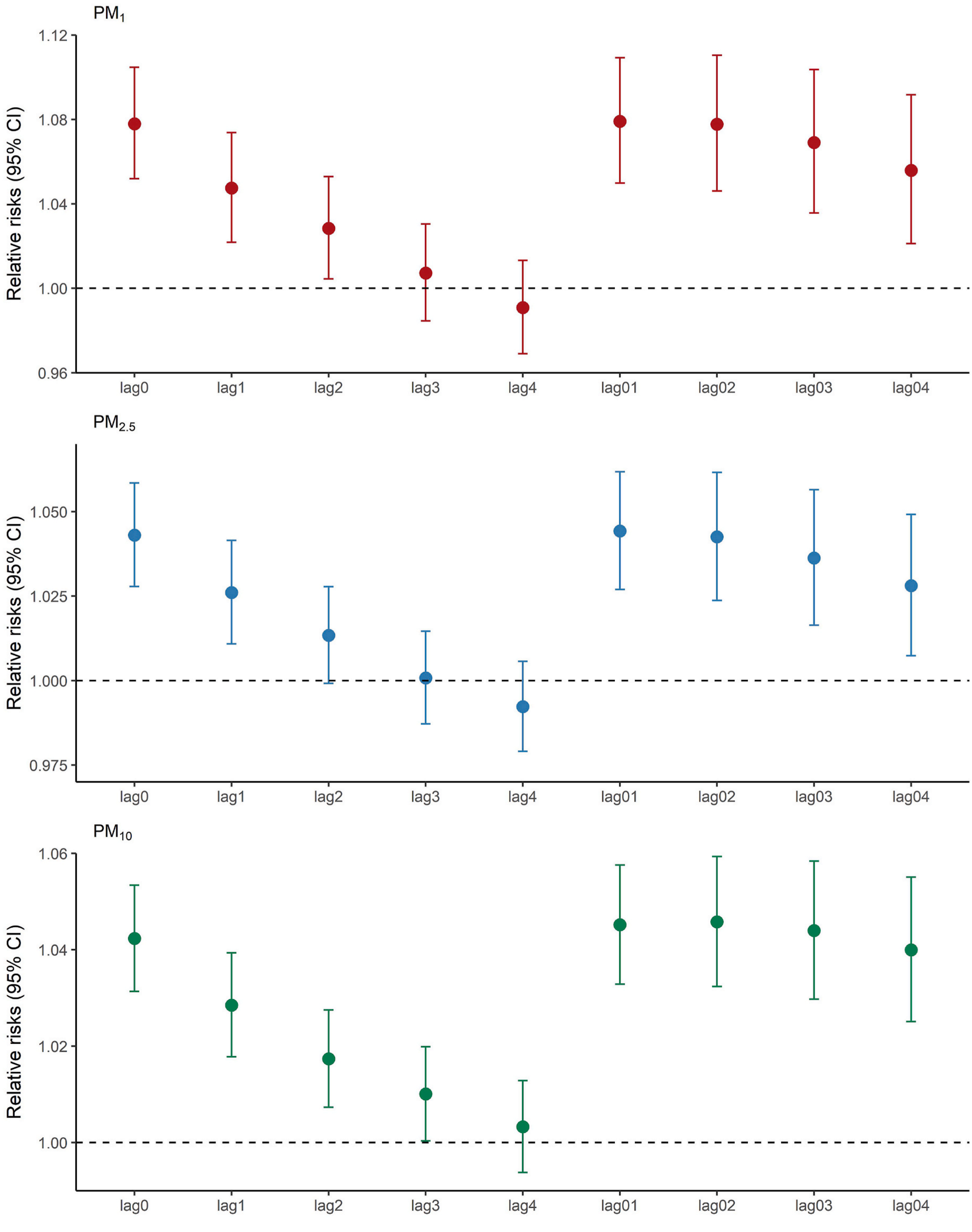

Fig. 1. Relative risk (with 95% CIs) of ILI cases at different exposure days for every 10 μg/m^3 increase in exposure to PM_1, $PM_{2.5}$ and PM_{10}. The x-axis represents PM measurements at several single-lag (lag0 to lag4) and moving-average (lag01 to lag04) days before illness onset. For instance, lag0 corresponds to the current day concentration, lag1 corresponds to the concentration of the day before illness onset; lag01 corresponds to the two-day moving averages of current and previous day concentrations of air pollutants.

modifying the degrees of freedom for time and meteorological variables. The effects of PMs on ILI with an IQR increase showed that, PM_{10} had the strongest effect, followed by PM_1 and $PM_{2.5}$ (Table S5).

4. Discussion

Influenza-like illness is a serious public health issue that annually accounts for a significant amount of morbidity and mortality. In addition, air pollution may affect respiratory infection and raise ILI incidence. In this study, we examined the associations between PM_1, $PM_{2.5}$, PM_{10} and ILI, and our findings suggested that the 3 p.m. pollutants mentioned above were associated with an increased risk of ILI. The adverse effects of air pollution on ILI varied by the size of particulate matter. Meanwhile, age and gender-specific subgroup analyses revealed

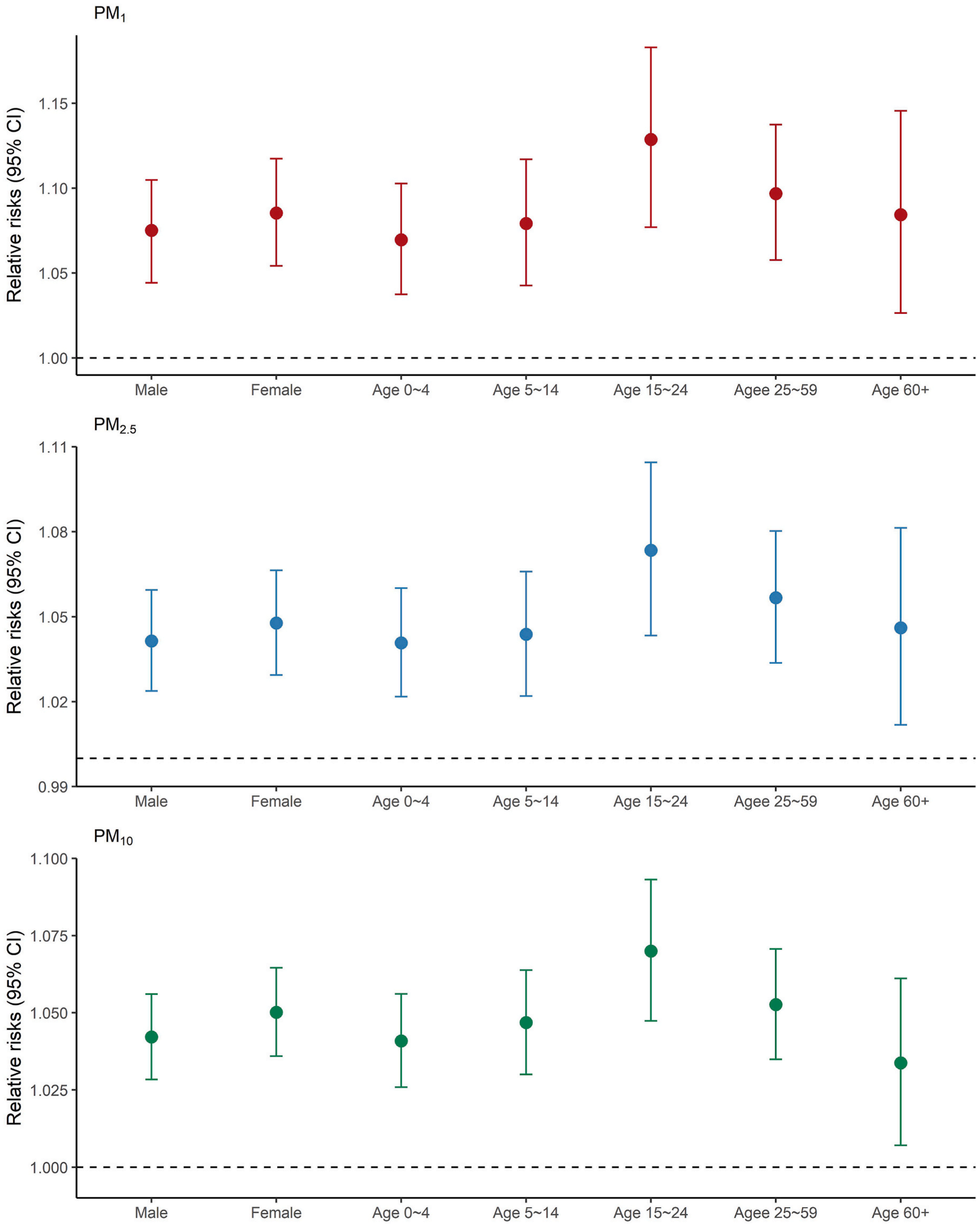

Fig. 2. Relative risk (with 95% CIs) of ILI cases among subgroups stratified by gender and age, associated with a per 10 μg/m^3 increase in exposure to PM$_1$ (lag01), PM$_{2.5}$ (lag01) and PM$_{10}$ (lag02).

comparable PM-ILI associations, with people between the ages of 15–24 being the most susceptible. These results would enrich the evidence about the link between PM pollutants and ILI.

The adverse effects of PM$_{2.5}$ and PM$_{10}$ on ILI have been consistently demonstrated by epidemiological studies (Chen et al., 2017; Huang et al., 2016; Liu et al., 2019; Su et al., 2019; Toczylowski et al., 2021); however, there is a lack of evidence regarding the impact of PM$_1$. We discovered significant associations between exposure to ambient PM$_1$ and increased ILI risks in Guangzhou. Potential mechanisms for the toxic effects on the human respiratory system may be that PMs could enhance airway responsiveness by inducing oxidative stress and inflammation (Ghio et al., 2012), which may weaken host immunological defenses and diminish susceptibility to bacterial and viral infections (Ciencewicki and Jaspers, 2007). Furthermore, the smaller size of PM$_1$ enables the pollutant to reach deeper into the respiratory system, thus harming the respiratory system more severely.

The health effects of PM pollutants vary depending on different particle size fractions, as well as source and chemical composition

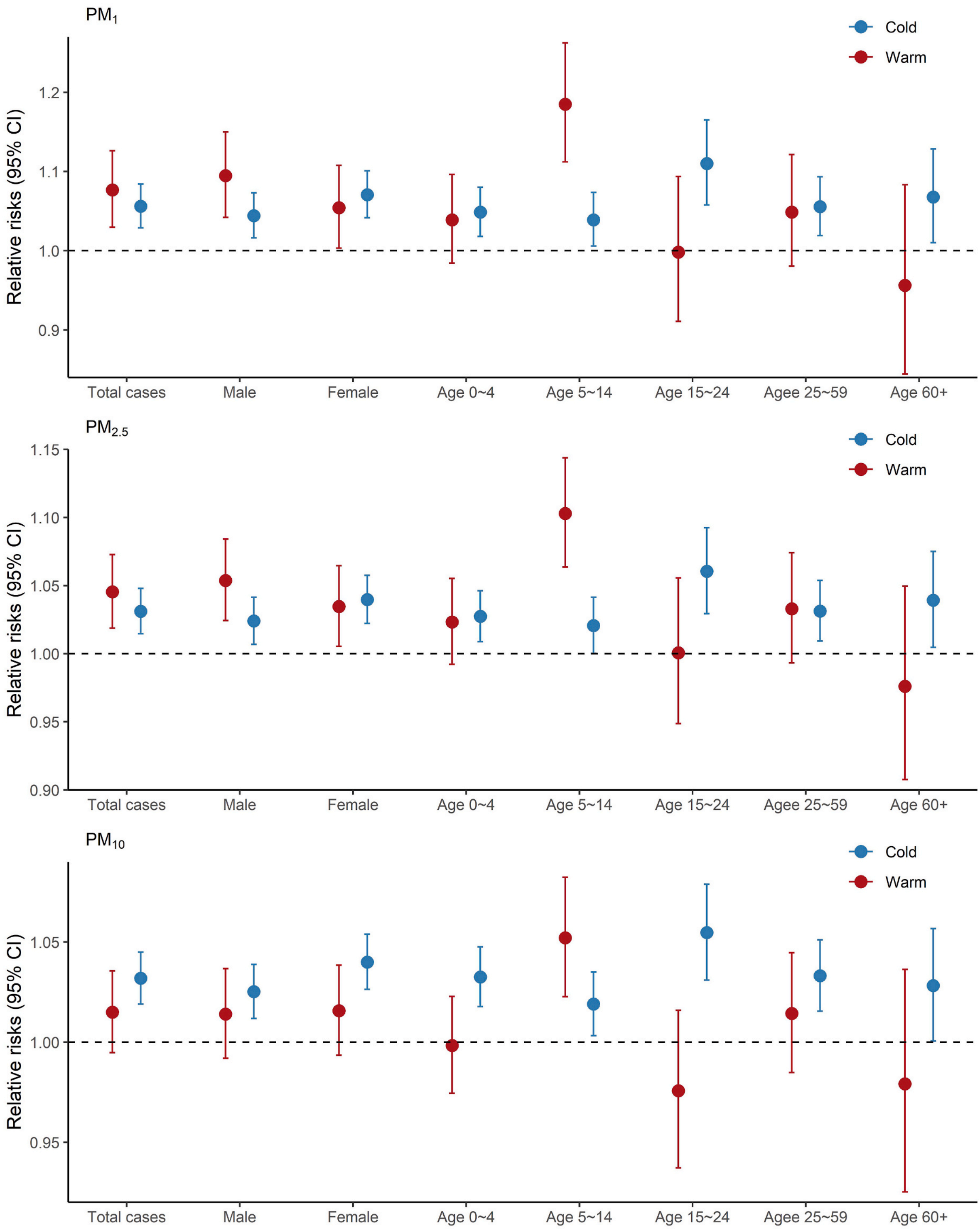

Fig. 3. Season-specific relative risk (with 95% CIs) of ILI cases by 10 μg/m^3 increase in exposure to PM$_1$ (lag01), PM$_{2.5}$ (lag01) and PM$_{10}$ (lag02).

(Frank and Julia C, 2012). Our findings were in line with earlier research, showing that PM$_1$ had stronger adverse health effects than PM$_{2.5}$ and PM$_{10}$ with an increase of 10 μg/m^3. For instance, Wang et al. reported that among PM$_1$, PM$_{2.5}$ and PM$_{10}$, PM$_1$ had the greatest impact on pneumonia hospitalisations (Wang et al., 2021). Meanwhile, Hu et al. (2018) and Lin et al., 2016b) found that PM$_1$, rather than PM$_{2.5}$ and PM$_{10}$, had a stronger associations with respiratory and cardiovascular mortality. Herein, Hu et al. indicated that by further comparing the ratio of PM$_1$/PM$_{2.5}$ concentration and attributable deaths, PM$_1$ accounts for 95% of the mortality caused by PM$_{2.5}$. PM$_1$ may consist of primary organic aerosols, ammonium, nitrate, sulphate, and chloride, which could be from coal combustion and traffic, cooking emissions (Niu et al., 2020). In addition, compared to PM$_{2.5}$, the proportion of PM$_1$ derived from combustion, such as burning biomass fuel, was substantially higher (Perrone et al., 2013). Despite the need for more research, these may be responsible for PM$_1$'s more powerful hazardous effects. However, when using an IQR increase as the magnitude of change, the PM$_1$ effect was no longer the strongest. More studies need to be conducted to verify whether PM$_1$ had stronger harmful impacts.

The largest impact of PM$_{2.5}$ on ILI was observed in this study at a

Table 3

Fractions and counts of ILI cases (stratified by gender and age groups), attributed to ambient PM_1, $PM_{2.5}$, and PM_{10} in Guangzhou.

Cases and subgroups	Attributable number of influenza cases (95% CI)			Attributable fraction (95% CI)		
	PM_1	$PM_{2.5}$	PM_{10}	PM_1	$PM_{2.5}$	PM_{10}
All cases	3190(1934, 4319)	5510(3319, 7692)	5176(4346, 6001)	1.43(0.88, 1.93)	2.48(1.44, 3.50)	2.33(1.97, 2.68)
Male	1687(982, 2420)	2889(1577, 4086)	2824(2268, 3329)	1.39(0.78, 1.95)	2.38(1.35,3.39)	2.33(1.88, 2.73)
Female	1540(908, 2163)	2682(1559, 3768)	2354(1932, 2780)	1.52(0.90, 2.08)	2.65(1.62, 3.70)	2.33(1.93, 2.73)
0–4 years old	870(416, 1263)	1737(838, 2546)	1069(823, 1290)	1.12(0.58, 1.65)	2.23(1.17, 3.33)	1.37(1.04, 1.67)
5–14 years old	1921(968, 2886)	2666(1199, 4146)	4170(3278, 5021)	2.16(1.09, 3.33)	3.00(1.29, 4.61)	4.69(3.72, 5.55)
15–24 years old	158(13, 275)	377(68, 663)	323(217, 403)	0.87(0.11, 1.53)	2.08(0.33, 3.71)	1.78(1.18, 2.24)
25–59 years old	209(113, 273)	715(395, 1031)	83(59, 90)	0.68(0.41, 0.90)	2.34(1.31, 3.35)	0.27(0.19,0.29)
60 years old and above	68(23, 98)	184(46, 301)	36(9, 45)	1.02(0.37,1.45)	2.74(0.77, 4.53)	0.54(0.14,0.67)

two-day moving average (lag01), with a 4.4% increase in daily cases. Similar to research from Hefei (Liu et al., 2019), which found that exposure to $PM_{2.5}$ increased ILI cases by 4.0%. However, the $PM_{2.5}$-related effect of ILI in our study was higher than those studies in Jinan (Su et al., 2019) and nationwide (Chen et al., 2017). The RR value of ILI was 1.046 with a 10 $\mu g/m^3$ increase of PM_{10} on lag02 days in our study, which was similar to a study in Nanjing (Huang et al., 2016). The effects of PMs on ILI in our study were significant during single lags of 0–3 days and multi-lags of 01–04 days. And the strongest effects were observed with a 2-day moving average of PM_1 and $PM_{2.5}$, and a 3-day moving average for PM_{10}. It was consistent with previous studies and can be explained by the incubation period of ILI-associated viruses. According to Lessler and his colleagues (Lessler et al., 2009), the median incubation period was 1.4 and 0.6 days for influenza A and influenza B, respectively. For other ILI-associated viruses such as rhinovirus and parainfluenza, the median incubation period was 1.9 and 2.6 days. The information about lag effects of PMs could be useful when proposing a strategy for the control and prevention of ILI.

The epidemiology of air pollution has given considerable attention to gender differences in the relationship between air pollution and respiratory health, although the results were mixed. Similar to that of Zhang et al., the effects of PM pollutants between gender were basically equivalent (Zhang et al., 2020), whilst other studies indicated that females may be more sensitive to PM (Bell et al., 2015; Di Q et al., 2017). In addition, children and the elderly are especially vulnerable to air pollution because of their relatively weakened immune systems (Wang and Chau, 2013). However, the results of this study showed that people aged 15–24 was shown to have a higher risk of ILI with exposure to PM pollutants. Similar results were also found in studies by Huang et al. (2016) and Samoli et al. (2011). Possible explanations include the fact that young children would spend less time outdoors than older ones, shielding them from exposure to air pollution. In contrast, adults and the elderly frequently prefer to self-administer medication unless their disease becomes severe or unmanageable. As a result, ILI monitoring statistics may not adequately reflect the incidence in these age groups. On the other hand, children (aged 6 months to 5 years) and elderly ($\geq$60 years) were recommended as a priority group for influenza vaccination in mainland China, and a study showed that the influenza vaccination coverage was higher among these age groups (Wang et al., 2018). This could protect them from being infected with influenza.

Herein, seasonal patterns of PM_1-and $PM_{2.5}$-ILI associations were stronger in the warm season than in the cold season, which were consistent with a previous study in Zhejiang Province (Hu et al., 2018). The higher effects in the warm season may be related to people being outdoors for a longer time (Calkins et al., 2007). Furthermore, studies have shown that the permeability of outdoor PM to the inside environment is increased by natural ventilation, and that the correlation between indoor and outside PM is larger in the summer than the winter (Peng et al., 2005). Nevertheless, other studies showed contradictory findings. A case-crossover study in Shenzhen identified larger effects for PM_1-and $PM_{2.5}$-associated risks of hospital admission for respiratory diseases in the cold season (Zhang et al., 2020). Another study also found that there was only a relationship between PM_{10} and emergency department visits during the cold season (Chen et al., 2019). Interestingly, the PM_{10}-ILI association was stronger in the cold season in our study. This might be the result of elements like the chemical composition and concentration of environmental PM, the exposure pattern of the population, and climatic conditions. Future studies, however, need delve deeper into the specific causes.

NO_2 and SO_2, which attenuated and lost significance in the two-pollutant models, proved to be confounding factors in the associations between PM_1 and $PM_{2.5}$ exposures and ILI. Other studies have also reported this phenomenon (Samoli et al., 2013; Zhao et al., 2017). It is challenging to assess the separate effects of PM_1, $PM_{2.5}$, and NO_2 because they are primarily traffic-derived contaminants (Tian et al., 2011) with substantial correlations.

Our study estimated the burden of ILI cases attributable to PM pollutants exposure, which yielded more appropriate information to estimate the potential health benefits of actions to enhance air quality. Such approaches have been applied to estimate the burden of mental disorders caused by PM exposure. This is the first study to evaluate the burden of ILI caused by PM pollutants, which gives policymakers specific information about the possible health benefits of lowering PM concentrations.

However, several limitations should also be acknowledged in this study. Firstly, exposure misclassification is inevitable because data were obtained from monitoring stations rather than personal exposure. Secondly, we could not identify their contributions to the risk of ILI because of data unavailability on specific chemical components of PMs. Thirdly, the ILI surveillance data may not be fully recorded, and the findings may not accurately reflect the population as a whole. Fourthly, because this study was limited to a particular city, it may be difficult to extrapolate from the findings. Hence, multi-regional studies will become increasingly important.

5. Conclusions

In summary, our study provided suggestive proof of the adverse effect of PM_1 on ILI cases. The health impacts of PMs on ILI were different between sizes of particulate matter. These findings could better understand the health effects of PM_1 and encourage the creation of public health policies to combat PM pollution. However, more research is required to establish the causality because the results from the current study are insufficient to accomplish so.

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Consent for publication

Not applicable.

Ethics approval and consent to participate

The ethics approval was waived by the ethics committee of Guangzhou CDC after consultation according to the law on the prevention and control of infectious diseases. Because cases should truthfully provide relevant information in the prevention of infectious disease, and the analytical data sets were constructed anonymously.

Declaration of competing interest

The authors declare that they have no competing interests.

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Not applicable.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2022.114074.

Abbreviations

PM	particulate matter
ILI	influenza-like illness
DALYs	disability-adjusted life-years
NO_2	nitrogen dioxide,
SO_2	sulfur dioxide,
O_3	ozone
CI	confidence interval
RR	relative risk
AN	attributable number
AF	attributable fractions

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