Journal of Travel Medicine
International Society of Travel Medicine
Promoting healthy travel worldwide
Established 1991
Journal of Travel Medicine, 2021, 1–13
doi: 10.1093/jtm/taab055
Advance Access Publication Date: 5 April 2021
Review

Review

Travelling to polluted cities: a systematic review on the harm of air pollution on international travellers' health

M. J. Ruzmyn Vilcassim, PhD[1], Amy E. Callahan, BS[2], and Kristina M. Zierold, PhD[1,*]

[1]Department of Environmental Health Sciences, University of Alabama at Birmingham, Birmingham, AL, USA and
[2]Department of Biostatistics, University of Alabama at Birmingham, Birmingham, AL, USA

*To whom correspondence should be addressed. Department of Environmental Health Sciences, School of Public Health, Room 534C, University of Alabama at Birmingham, Birmingham, AL 35294-0022, USA. Tel.: +15022169673; Email: kzierold@uab.edu

Submitted 5 October 2020; Revised 23 March 2021; Editorial Decision 24 March 2021; Accepted 30 March 2021

Abstract

Rationale for Review: In 2019, approximately, 1.4 billion people travelled internationally. Many individuals travel to megacities where air pollution concentrations can vary significantly. Short-term exposure to air pollutants can cause morbidity and mortality related to cardiovascular and respiratory disease, with the literature clearly reporting a strong association between short-term exposure to particulate matter ≤2.5 μm and ozone with adverse health outcomes in resident populations. However, limited research has been conducted on the health impacts of short-term exposure to air pollution in individuals who travel internationally. The objective of this systematic review was to review the evidence for the respiratory and cardiovascular health impacts from exposure to air pollution during international travel to polluted cities in adults aged ≥18 years old.
Key Findings: We searched PubMed, Scopus and EMBASE for studies related to air pollution and the health impacts on international travellers. Of the initially identified 115 articles that fit the search criteria, 6 articles were selected for the final review. All six studies found indications of adverse health impacts of air pollution exposure on international travellers, with most of the changes being reversible upon return to their home country/city. However, none of these studies contained large populations nor investigated vulnerable populations, such as children, elderly or those with pre-existing conditions.
Conclusions: More research is warranted to clearly understand the impacts of air pollution related changes on travellers' health, especially on vulnerable groups who may be at higher risk of adverse impacts during travel to polluted cities.

Key words: Air pollution, particulate matter, ozone, international travel, travellers' health

Introduction

The health impacts from air pollution exposure are staggering and well documented. The Lancet Commission on Pollution and Health[1] reported that in 2015, global estimated deaths due to ambient particulate air pollution (PM) and ozone (O_3) were 4.2 and 0.3 million deaths, respectively. The World Health Organization (WHO) estimated that in 2016, 58% of outdoor air pollution-related premature deaths were due to coronary heart disease (CHD) and stroke, 18% of deaths were due to chronic obstructive pulmonary disease (COPD) and acute lower respiratory infections and 6% of deaths were due to lung cancer.[2] Considerable research has assessed long-term exposure to $PM_{2.5}$ (particulate matter with aerodynamic diameter ≤2.5 μm/fine PM) and O_3 on cardiovascular and pulmonary health and mortality. However, knowledge about the health consequences of short-term exposures, especially in developing countries, is still growing.

Anthropogenic air pollution is a major environmental problem in large cities in the world, particularly released from, and impacting urban areas. According to the United Nations,[3] more people now live in urban areas than in rural areas, comprising ~55% of the world's population. This trend towards urbanization is expected to grow, leading to an increase in population sizes in existing megacities as well as the creation of new megacities.[3,4] According to the United Nations, a megacity is defined as a metropolitan area with a population of more than 10 million people.[3] Many megacities are popular travel destinations with large numbers of annual tourist arrivals.[5]

© International Society of Travel Medicine 2021. Published by Oxford University Press. All rights reserved. For Permissions, please e-mail: journals.permissions@oup.com

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023

Until the coronavirus disease 2019 (COVID-19) pandemic, international tourist arrivals had been steadily increasing with approximately 1.4 billion worldwide arrivals in 2019.[6] The greatest proportion of the 2018 arrivals were for leisure, recreation and holidays (56%) followed by visiting friends, health, religion, etc. (27%), and 12% was for business and professional travel.[6] Thus, international stays are often relatively short visits to popular destinations, with an increasing proportion of travellers spending time in urban environments.[6,7] Therefore, travellers are more likely to experience health events from exposure to short-term air pollution variations, such as daily or weekly pollution peaks, compared to the resident populations of a city. Although billions of individuals travel internationally, there is limited research addressing the impact of air pollution on travellers' health. Thus, the objective of this systematic review was to evaluate the existing evidence on the respiratory and cardiovascular health impacts of exposure to elevated levels of air pollution in adults (≥18 years) during international travel.

Background

Air pollution concentrations in megacities with the greatest number of arrivals

Dense populations combined with high energy demand have led to the increased use of fossil fuels, resulting in elevated levels of air pollution in megacities.[8,9] The air pollution profiles of such cities are dependent on the types of sources (i.e. industrial, vehicular and natural), impact of weather/climatic conditions, topography and other regional factors. In recent times, air pollution has become one of the major environmental concerns, often exceeding 5–10 times the WHO guidelines for extended periods in some megacities.[9]

During international travel, especially to such polluted cities, individuals may be exposed to a large differential of PM and O_3 concentrations and might lack the knowledge and adaptations to minimize the risk of acute health events. For example, a traveller from a North American or European 'clean' city who travels to Beijing during the winter period may be exposed to 5–10 times the $PM_{2.5}$ concentrations that they would normally experience in their home cities. This change frequently happens within a matter of hours or days, increasing the risk of acute respiratory and cardiac injury.

Air pollution levels in megacities. Fine PM concentrations vary significantly among megacities across the world. Tables 1 and 2 report the annual average concentrations of $PM_{2.5}$ (2019 and 2020) for countries with the highest travel arrivals (2018) and for selected megacities throughout the world.

Figure 1 displays a map of the world with the most recent $PM_{2.5}$ data. The map indicates that travellers may encounter higher pollution levels when travelling from Northeast and European megacities to Asian or South American cities.

Data from the period of 2010–20 demonstrate that North American and European megacities generally have lower average $PM_{2.5}$ concentrations compared to the megacities in South and East Asia and South America.[9–11] $PM_{2.5}$ levels in South and East Asian cities are approximately 3–5 times higher than the average concentrations of North American and European cities, including New York City (NYC), Los Angeles and London.[10,12–14] Interestingly, NYC is among the five least polluted megacities in the world.[12] Studies from East Asia (primarily Beijing and Shanghai) report higher daily average concentrations ranging from 52.7 μg/m^3 to average concentrations exceeding 100 μg/m^3 [13–20], which are several times higher than the WHO's annual and daily guidelines (10 and 25 μg/m^3, respectively) for $PM_{2.5}$. However, Hong Kong and Tokyo have relatively lower PM concentration when compared to Beijing and Shanghai.[21–24] New Delhi and Cairo have been identified as the most polluted megacities, respectively, followed by relatively smaller cities in China, such as Xi'an, Tianjin and Chengdu.[12] Among South American megacities, Mexico City is considered one of the most polluted in the world, although in recent times, it has seen improvements in air quality.[25]

Ozone, a major gaseous pollutant, can vary markedly within a short period, but trends closely follow that of $PM_{2.5}$. For example, O_3 levels (estimated) were found to be within the United States Environmental Protection Agency's (US EPA) standard of 70 ppb (8-h) in NYC and Los Angeles.[26] However, in China, the daily 1- and 8-h maximums and the daily average of O_3 concentrations were several times higher, with concentrations close to or above the WHO 8-h standard of 100 μg/m^3 and with the maximum peak concentrations exceeding 300 μg/m^3 in Beijing.[16,27]

Sources of air pollution in megacities. $PM_{2.5}$ constituents can be used to reveal possible sources that contribute significantly to air pollution using source apportionment studies.[28–31] For example, major sources and key elements identified in one study in the USA included: the metals industry (lead and zinc); crustal/soil particles (calcium and silica); motor vehicle traffic [elemental carbon (EC) and nitrogen dioxide]; steel industry (iron and manganese); coal combustion (arsenic and selenium); oil combustion (vanadium and nickel); salt particles (sodium and chlorine) and biomass burning (potassium).[29] In addition to the primary particles released from sources, secondary particles and gases can contribute significantly to the air pollution in a city. For example, traffic is a source of primary pollutants,[32] which under atmospheric conditions (sunlight, humidity, etc.) can react to form secondary particles as well as secondary gaseous pollutants such as O_3.[33] In some regions, natural sources of pollutants or phenomena such as smog events and mineral dust storms from deserts can elevate the air pollution levels.[34]

Chinese megacities are frequently among the global cities with the highest air pollution levels.[35] In such large and polluted cities, pollution profiles can differ between the urban and suburban areas, with secondary particles leading in suburban areas and with traffic emissions and coal combustion being the leading contributors in urban areas.[36] Urban areas characteristically have higher concentrations of EC, particulate organic matter and gaseous pollutants, which are related to traffic.[37–39]

Over the past 5 years, megacities in South Asia have gained notoriety due to very high air pollution levels. In addition to traffic and industrial sources, other human activities, such as agriculture, can be a source that significantly impacts air quality. Data from the WHO, government agencies and recent studies have all shown that New Delhi ranks as the most polluted megacity, if not among the top 10 most polluted cities in the world.[9,12,40]

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023

Table 1. Annual average concentrations of $PM_{2.5}$ for 2019 in selected countries with the highest travel arrivals

Country	$PM_{2.5}$ average (μg/m^3)	US EPA NAAQS for $PM_{2.5}$	WHO air quality guideline for $PM_{2.5}$
USA	7.8	12 μg/m^3 (Annual)	10 μg/m^3 (Annual)
England	10.1	35 μg/m^3 (24 h)	25 μg/m^3 (24 h)
France	11.4		
Brazil	11.7		
Argentina	13.5		
Japan	13.5		
Mexico	20.1		
China	47.7		
Egypt	67.9		
India	83.2		

Data source: State of Global Air (https://www.stateofglobalair.org).

Table 2. Annual average concentrations of $PM_{2.5}$ in year 2020 in selected megacities that are also the most popular travel destinations

Country	City	$PM_{2.5}$ average (μg/m^3)	Population (thousands)	International travellers in 2018 (thousands)
USA	NYC	8.6[a]	18 819	13 500
USA	Los Angeles	13.3[a]	12 458	7246
England	London	9.9[b]	9046	20 716
France	Paris	13.9[b]	10 901	16 837
Brazil	Rio De Janeiro	NA	13 293	2305
Argentina	Buenos Aires	10.2[a]	14 964	2373
Japan	Tokyo	NA	37 468	9896
Mexico	Mexico City	26.0[c]	21 581	2434
China	Beijing	39.7[a]	19 618	3767
China	Shanghai	28.0[a]	25 582	18 551
Hong Kong/China	Hong Kong	23.3[c]	7429	29 827
Egypt	Cairo	NA	20 076	4893
India	New Delhi	79.3[a]	28 514	12 505
India	Mumbai	41.1[a]	19 980	10 670

Data sources: [a]US Embassy air monitoring sites located in cities abroad; [b]open source data from www.openaq.org—may include central monitors and/or other monitoring methods; [c]data from local low-cost sensor networks (www.purpleair.com).
Note: Concentration obtained from US EPA/US Embassy monitors is considered the most accurate. The US EPA NAAQS and the WHO air quality guideline for $PM_{2.5}$ are 12 and 10 μg/m^3, respectively (annual average). NA, data not available.

While studies on New Delhi's air pollution sources are limited, news reports and available articles attribute crop burning in bordering states, dusty winds from the gulf region, high traffic density combined with low-quality fuel, over-population, large-scale construction and local weather conditions/inversions during the peak period as key reasons for air pollution.[41,42]

Changes in air pollution levels in megacities during the COVID-19 pandemic. Due to the global COVID-19 pandemic, governing bodies around the world imposed strict restrictions, severely limiting human mobility and impacting domestic and international travel. In several large cities, $PM_{2.5}$ concentrations dropped during the lockdown period compared to the previous months of 2019.[43–47] Compared to the 2019 averages in March, $PM_{2.5}$ levels decreased by 14% in Mumbai, 4% in Los Angeles and 32% in NYC, which were not only attributed to lockdowns but also to rainfall in NYC.[43] An analysis of 367 cities in China demonstrated that the mean daily $PM_{2.5}$ concentration decreased by 18.9 μg/m^3 during the quarantine period (February 10–March 14) compared to the pre-quarantine month of January.[48] Interestingly, O_3 concentrations increased in some regions in China, including Shanghai, during the lockdown by ∼20%.[49]

$PM_{2.5}$ and O_3 concentrations in four major cities in India (including New Delhi) had an overall declining trend from the beginning of the lockdown in March through different phases of the lockdown until mid-May.[50] North India, as a whole, experienced a 34% decrease in $PM_{2.5}$ concentration compared to 2019, however, O_3 concentrations increased.[44] Ozone in New Delhi, increased temporarily (during April–May) compared to the previous phase. This could be a direct result of the lockdown and strict curfews which were nationwide, but it may have also been impacted by the weather conditions.[50]

Despite the expectation of significant reduction in all air pollutants due to the lockdowns, not all cities experienced reduced levels. During the initial period of the lockdown in China (23 January 2020–13 February 2020), some northern regions saw an increase in the concentrations of $PM_{2.5}$. $PM_{2.5}$ in Northern China (including in Beijing) rose compared to other regions, possibly due to severe haze events. During this time, the maximum daily level reached 274 μg/m^3 with a mean increase of 30.6 μg/m^3 compared to the previous year.[51] Toyoko's $PM_{2.5}$ concentration increased by 11%, however, there was not a mandatory quarantine, but the government requested for teleworking.[52] London and Paris both reported increased levels of

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023

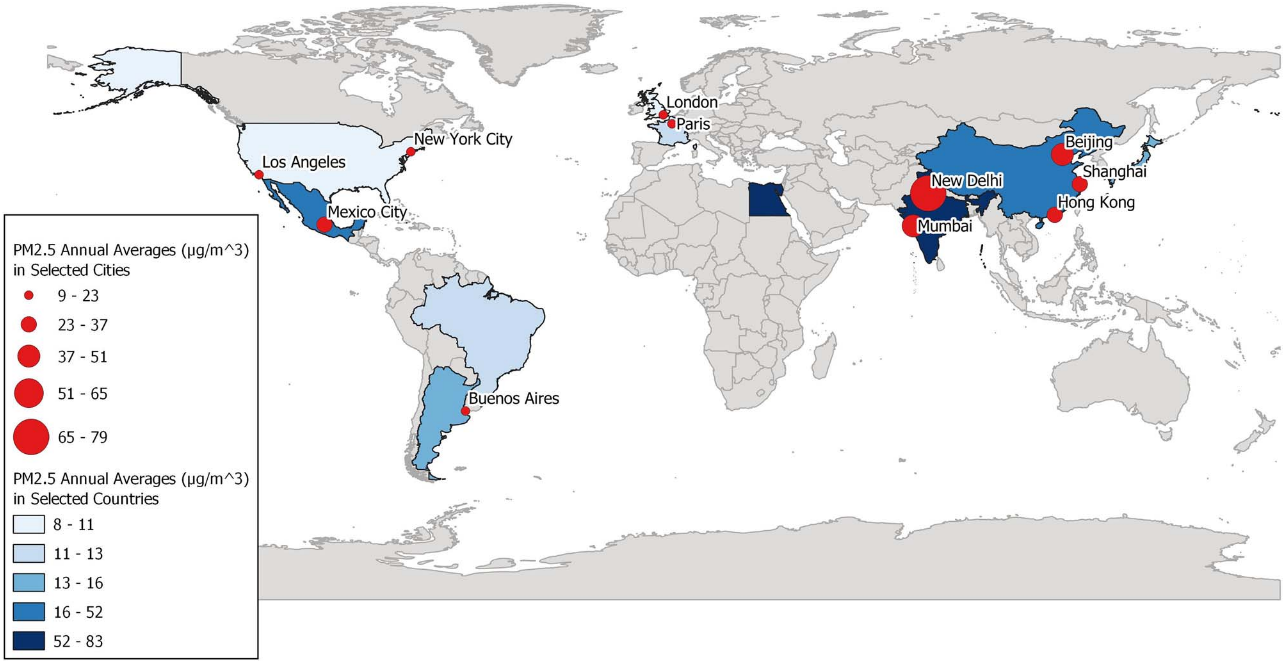

Figure 1. Annual average concentrations of $PM_{2.5}$ (µg/m$^{3)}$ in selected megacities (2020) and countries (2019) with the highest travel arrivals.

$PM_{2.5}$ during the quarantine period.[52] Researchers have highlighted the importance of other sources and phenomena, mainly industry, agriculture and the impact of meteorological events on air pollution level changes.[53]

Short-term exposures and health effects

Of importance to international travellers are the health events that occur from short-term changes in pollutant concentrations that impact cardiovascular and respiratory events. This section highlights research that has been conducted on residents living in megacities, as it provides an important perspective into potential health events that travellers may experience, particularly, if the travellers are arriving from destinations with lower pollutant concentrations and/or if the travellers have pre-existing conditions.

Continuous exposure to air pollution, such as that occurs in residents living in polluted cities, can cause chronic injury and physiological changes to the respiratory and cardiovascular system, leading to increases in the incidence and prevalence of chronic diseases, such as asthma, COPD, heart disease and cancer in the population. Short-term exposures and peaks (as experienced by travellers) can be associated with acute effects, which may include short-term lung function decrements, increase in respiratory symptoms, increase in airway oxidative stress and cardiovascular events, such as hospital admissions for heart failure (HF), events related to pre-existing CHD and heart attacks.

The impact of air pollutants on human health can vary based on the exposure time, underlying health conditions, age, sex and season of travel. Therefore, in order to understand and compare the findings, these factors need to be taken into consideration.

Cardiovascular diseases. Globally, cardiovascular diseases (CVDs) are the leading cause of death, and over 75% of deaths occur in low- and middle-income countries.[54] Research focuses on different CVD events, such as HF, hospital admissions due to CHD and heart attacks.

$PM_{2.5}$ exposure Research from Beijing, Shanghai and Hong Kong, where mean daily concentrations of $PM_{2.5}$ are considerably higher compared to developed nations, consistently report that increases in $PM_{2.5}$ are associated with increased CVD events (i.e. hospital admissions, outpatient visits emergency room visits and out-of-hospital heart attacks).[13,14,16–18,22,38,55–67] Although the research is remarkedly consistent showing a positive association between short-term exposure to $PM_{2.5}$ and CVD events, the findings vary across specific CVD events and exposure times.[14,16,17,65]

Outside of Asia, researchers have reported mixed associations between the daily exposure to $PM_{2.5}$ and CVD events.[68–71] In NYC, an increase of 10 µg/m^3 of $PM_{2.5}$ during a cumulative exposure over 2 days caused a 6.2% increase in CVD hospitalizations.[70] However, in other studies, the total $PM_{2.5}$ was not associated with CVD, but individual sources [e.g. EC, black carbon (BC)] were associated with increased hospital admissions, indicating the importance of composition on health outcomes.

Of interest to travellers, who spend several days in polluted cities, is that cumulative days of exposure to $PM_{2.5}$ often led to greater increases of CVD events.[13,14,16,17,67,70] Several studies have shown that increases in hospital admission or emergency department visits for HF and CHD associated with cumulative $PM_{2.5}$ were greater than the increases for single-day exposure.[13,14,16,17]

Morbidity is not the only concern. In residents of Asian megacities, increases in CVD deaths from short-term exposure are also reported.[14,17,21–23,25,38,72–75] When increases in $PM_{2.5}$ occur, mortality increased by a range of 0.25–2.35%. The differences in percent mortality increases were due to the difference

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023

in the exposure periods observed (e.g. one day before death vs. day of death).

Ozone exposure Research on CVD events and exposure to short-term O_3 is lacking compared to research on $PM_{2.5}$, but the studies that have been conducted show no significant associations between short-term O_3 exposure and CVD events.[18,63,76] Research regarding mortality from CVD events and short-term O_3 exposure is mixed.[21,77–80] Variations by country, exposure periods and the adjustment for other pollutants may lead to these conflicting findings.

Respiratory function and diseases. Respiratory conditions affect millions of individuals and are the leading causes of death and disability worldwide.[81] COPD is consistently ranked as one of the top four causes of death throughout the world.[82]

$PM_{2.5}$ exposure Studies on the relationship between short-term exposure to $PM_{2.5}$ and respiratory morbidity are relatively consistent in their findings that exposure to $PM_{2.5}$ increases adverse respiratory events.[14,19,68,75,83–89] Increased hospital admissions for COPD and decreased lung function in patients with COPD occurred when there were increases in $PM_{2.5}$.[19,83–85,87] Throughout the world, researchers have reported that hospital admissions for asthma increased with increased $PM_{2.5}$ levels.[68,86,88,89] Studies that reported findings of mortality and short-term exposure to $PM_{2.5}$ found increases in respiratory mortality in individuals exposed to short-term $PM_{2.5}$.[20,23,90]

Ozone exposure Multiple studies have investigated the relationship between O_3 and respiratory outcomes, with mixed findings, based on the participant's underlying health conditions, location and time period for exposure.[27,83,84,86,91–97]

When assessing respiratory events, studies from Asia consistently report that asthma admissions to hospitals is associated with increasing ozone exposure,[88,97] however, European studies report inconsistent findings.[96,98,99] For example, studies on COPD hospital admissions and exposure to O_3 have reported conflicting outcomes,[83,87 100] with some reporting increased hospital admission for COPD when O_3 increased[87,100]; while the others did not show a significant effect on the percent change in admissions.[83]

Mortality and O_3 has been investigated, producing conflicting findings.[78–80] Respiratory deaths were significant with increased ozone in Mexico City and Rio de Janeiro, but not in London.[78,80]

Age, sex and seasonal differences in exposure and health. When investigating season, age and sex differences, most researchers found that older individuals were more likely to experience a CVD or respiratory event or death.[17,18,21,55,56,72,78,83] However, results are conflicting regarding sex differences and health events. In some studies, females were reported to experience more adverse events,[14,17,21,55] while in other studies, males were more at risk.[13,18,63,72,83]

Most studies report that there are seasonal differences in health outcomes,[13,16,18,56,58,65,77,78,83,100] although the findings are mixed. The majority of these studies determined that there were more CVD and respiratory events in the cold season.[13,18,27,58,65,77,78,92] However, others have found no season differences or higher CVD events from $PM_{2.5}$ and O_3 in the warm season.[16,83]

Health outcomes and COVID-19 and air pollution. PM has been shown to increase the virus transmission[101] and mortality[102] of infectious diseases like influenza; therefore, the concept of increased transmission of COVID-19 from pollution is probable. Two questions arise when considering the interaction between air pollution, COVID-19 and health: (i) Does air pollution increase COVID-19 cases? and (ii) Does exposure to air pollution increase COVID-19 fatalities?

Air pollution and COVID-19 Several studies have investigated whether air pollution is associated with higher COVID-19 cases and fatalities.[48,103–109] Most have found significant associations between increases in air pollution and increased COVID-19 cases and deaths. In China, researchers reported that the air quality index, $PM_{2.5}$ and O_3 were positively associated with increased cases of COVID-19.[105,108] A 10 μg/m^3 increase in $PM_{2.5}$ and O_3 was associated with a 2.24 and 4.76% increase in the daily counts of COVID-19 cases.[109]

In London, UK, and in California, USA, researchers reported correlations between $PM_{2.5}$ concentrations and reported COVID-19 cases.[104,106] However, in NYC, the findings on the impact of $PM_{2.5}$ and O_3 with COVID-19 were mixed.[47] A one-unit increase in the moving average of O_3 was associated with a 10.5% increase in daily new COVID-19 cases; however, a one-unit increase in the moving average of $PM_{2.5}$ was associated with a 33.1% decrease in daily new COVID-19 cases.

Overall, research has shown that increases in $PM_{2.5}$ were related to increased mortality from COVID-19 and decreases in $PM_{2.5}$ were related to reduced mortality.[44,48,104,106,107,110,111] In one study, Yao *et al*.[107] found that for every 10 μg/m^3 increase in $PM_{2.5}$, the case fatality rate increased by 0.24%. In a study done in Italy, more polluted cities had two times higher the mortality rate when compared with less-polluted cities.[110]

Methods

This systematic review which focused on air pollution and travellers' health was conducted based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was registered in the Prospective Register of Systematic Reviews (PROSPERO) (CRD42020200420).

Types of participants and outcomes measured

The population of this review was adults aged ≥18 years who had travelled internationally. There were no restrictions on where the participants travelled and there were no restrictions on the reason for travel. The primary focus was on articles related to respiratory and cardiovascular outcomes, but articles that were related to other biological and physiological changes related to air pollution exposure were also included.

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023

Data sources and search strategy

We identified articles for this review using three databases: Embase, PubMed and Scopus. Supplementary Table S1 (available as Supplementary data at *JTM* online) reports the search terms we used for each database. Only original research articles, research letters and research communications that were published from January 2010–10 March 2020 were included. Conference abstracts, unpublished studies, review articles or correspondence (e.g. editorials and non-research letters) were excluded. We retained only articles written in English.

Criteria and process of article selection

Criteria for article selection were as follows: (i) populations who travelled internationally and not within areas of the same country (i.e. New York to Los Angles), (ii) populations aged ≥18 years of age, (iii) articles that had population demographics, specifically age and sex, (iv) data and information about pre-travel health related to the outcome being studied, (v) articles with $PM_{2.5}$ and O_3 as pollutant exposure and (vi) respiratory and cardiovascular health outcomes related to short-term exposure (defined as: 1 day–2 months) to air pollution.

Articles that were excluded from this review included: (i) those without international travellers, (ii) children defined as <18 years of age and (iii) articles without any health outcome provided.

Two authors, K.M.Z. and M.J.R.V., independently screened the records for inclusion and were blinded to each other's decisions. After the researchers screened the articles, they discussed their decision on whether to keep or remove an article. The reviewers first removed articles based on titles, then abstracts and then by reading the full paper. Disagreements were resolved by discussing the decisions of the reviewers. All decisions were recorded in Excel. In addition to the database searches, we reviewed the reference lists from the selected articles to identify any potential missing studies on air pollution and international travellers' health.

Data extraction and synthesis

For each article that remained, the following characteristics were extracted: author's last name, year of the publication, starting location, travel location, duration of travel, sample size, age range, sex, smoking status and outcome studied. The number of articles that remained for this review is small; the study designs are not similar, and the outcome measures varied, therefore, results could not be pooled for a meta-analysis.

Results

Article selection

A total of 115 English language publications were identified after applying the search terms and publication year range. Figure 2 reports the process that the authors used to remove studies from this list that did not meet the criteria (Criteria and process of article selection section).

After completing all the steps shown in Figure 2, six studies remained for assessing the impact of air pollution on the travellers' health. Characteristics of the studies are shown in Table 3.

All six studies included in the review were observational studies, which comprised of one case report and five longitudinal studies. All except one study investigated the health impacts of healthy non-smoking volunteers who travelled from a North American or European city to cities in East Asia, South Asia or Europe (i.e. one study[10] included participants who travelled from North America to Europe in addition to East and South Asia, and one study had participants who travelled from Japan to China). The age range of the participants was 18–57 years, although most participants were young adults below 30 years. Health outcomes measured included cardiopulmonary health endpoints (PEF and FEV_1) and blood and urinary biomarkers of air pollutant exposure. Most studies also used questionnaires to record symptoms, travel details and other information, such as diet, cooking behaviours and traffic conditions.

Health effects of air pollution on international travellers

Cardiopulmonary health outcomes and symptoms. Three studies investigated the cardiopulmonary health outcomes associated with travel to polluted cities. Vilcassim *et al*.[112] reported that a participant who travelled from NYC to Shanghai did not experience lung function (PEF) reduction in the first week in Shanghai when the $PM_{2.5}$ concentrations were not higher (approximately, 20 μg/m^3) than the typical concentrations in NYC. However, in the last week of stay in Shanghai, $PM_{2.5}$ levels reached a weekly or daily mean of 50 μg/m^3, with peak concentrations of up to 130 μg/m^3. During this last week, the participant experienced a drop in PEF (∼5%), which was accompanied by an increase in respiratory symptoms, including throat irritation and cough.

Further evidence of international travel-related air pollution impacts on cardiopulmonary health was reported.[10] Researchers studied a cohort of 34 volunteers who travelled from the USA (NYC metropolitan area) to various cities around the world. Young, healthy non-smoking volunteers provided repeated daily measures of FEV_1 before travel, during their stay abroad and after returning to their home city. Overall, increasing travel-related $PM_{2.5}$ concentration was associated with statistically significant decrements in lung function (FEV_1 and PEF). The highest decrease in lung function was observed when the participants travelled to highly polluted cities (defined as cities with $PM_{2.5}$ concentrations >100 μg/m^3), which included mostly South and East Asian cities, such as New Delhi, Shanghai, Beijing and Dhaka.

Participants who travelled to highly polluted cities also experienced a significant increase in respiratory symptoms, including cough, throat irritation and nasal congestion, requiring some individuals to use medication to manage their symptoms. Importantly, over 75% of the participants who experienced increased respiratory symptoms recovered from these adverse effects after returning home. In participants who had lung function decrements, return to their home city was associated with a significant mean increase (recovery) in FEV_1.[10] A reduction in lung function (including reversible) in combination with respiratory symptoms

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023

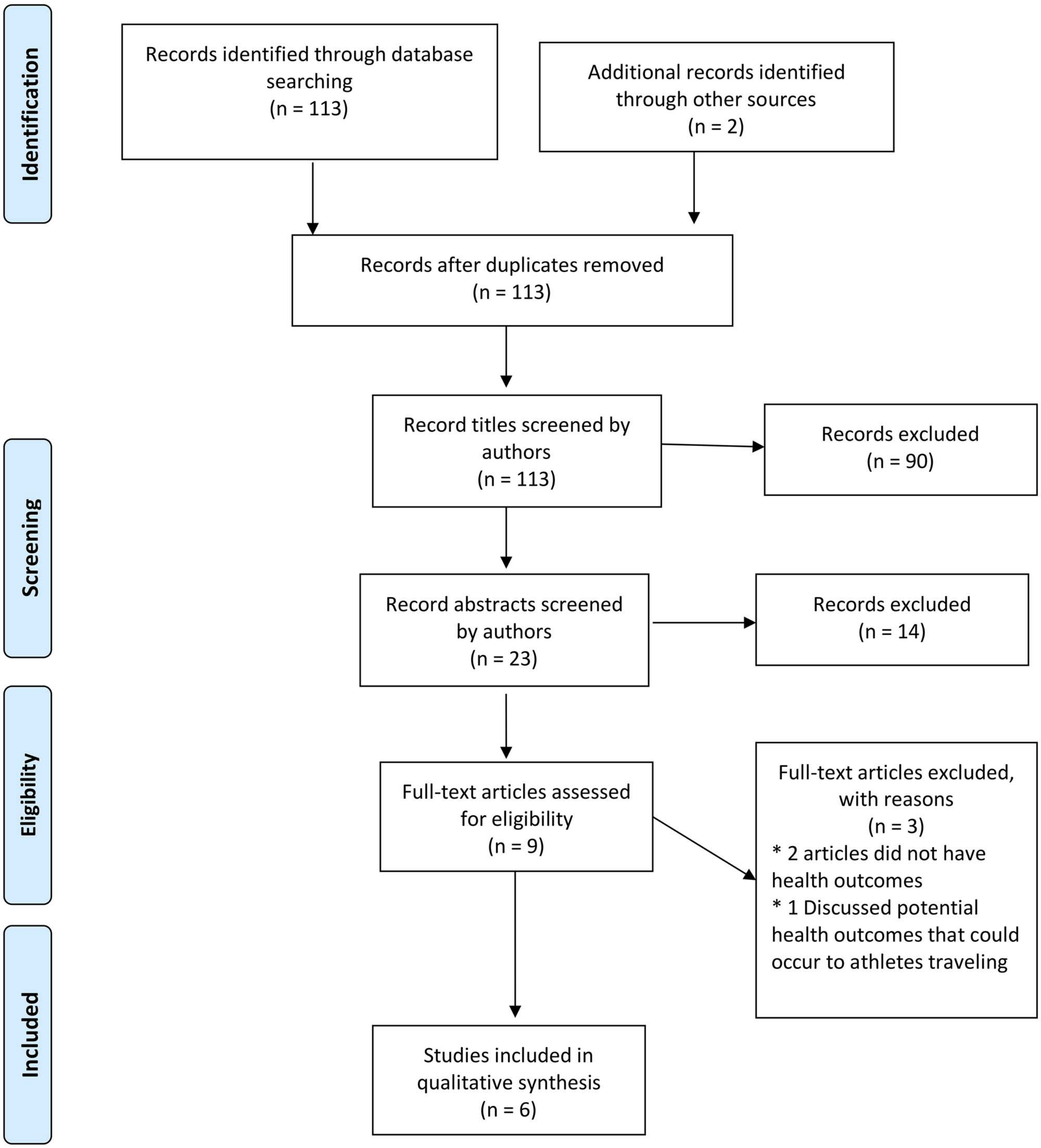

Figure 2. PRISMA flow diagram for air pollution and international travellers' health.

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023

is considered an adverse effect as per the American Thoracic Society (ATS) recommendations.[113]

Travel to polluted cities was also shown to be associated with adverse effects on cough reflex and cough-related quality of life due to travel-related PM exposures.[114] However, this study included smokers and non-smokers, and there was no stratification or controlling for smoking; therefore, determining if the changes in lung function were associated with changes in air pollution is difficult.

Urinary and blood biomarkers of exposure to air pollution. The possible mechanisms behind the health effects associated with travelling to polluted cities were investigated by Lin *et al*. in two studies.[11115] The first study investigated the difference in urinary biomarkers associated with polycyclic aromatic hydrocarbons (PAH) exposure in a group of 10 healthy volunteers who travelled from Los Angeles to Beijing in 2012.[115] The median concentrations of 12 hydroxylated PAHs in Beijing were significantly higher than Los Angeles, indicating higher exposure to pollutants

Table 3. Characteristics of studies included in review

First author, year of publication	Travel	Duration of travel	Sample size	Age, Smoking Status, Health Status, Number of Females	Outcome studied
Lin, Y., 2016[115]	Los Angeles, USA, to Beijing, China	10 weeks	10	Mean = 23.3 years Range = 20–39 Non-smoking, healthy, 6 females	Metabolites of PAHs, MDA Urinary biomarkers
Sato, R., 2016[114]	Sendai, Japan, to Beijing, China	2–8 days	17	Mean = 35 years Range = 25–57 Current smokers (2) Former smokers (5) Never-smokers (10), healthy, 7 females	Cough reflex Lung function
Wu, X., 2017[116]	Munich, Germany, to China	8–40 days	9	Mean = 29 years Range = 26–34 Non-smoking, healthy, 0 females	Oxidative stress biomarkers
Vilcassim, M. J. R., 2018[112]	NYC, USA, to Shanghai, China	2 weeks	1	31 years non-smoking, healthy, female	Lung function
Vilcassim, M. J. R., 2019[10]	NYC, USA, to 11 cities in Europe, 4 cities in South Asia, 4 cities East Asia, 1 city in Africa	At least 1 week	34	Mean *F* = 27.3 years Mean *M* = 26.6 years Range = 22–39 Non-smoking, healthy, 23 females	Lung function Blood pressure Heart rate Variability
Lin, Y., 2019[11]	Los Angeles USA, to Beijing, China	10 weeks	26	Mean = 23.8 years Non-smoking, healthy, 14 females	Metabolites of PAHs Urinary/blood biomarkers of CVD

in Beijing. The second study[11] measured urinary and blood biomarkers in a group of 26 non-smoking young adult travellers who were residents of Los Angeles and had travelled to Beijing.[11] The travellers spent 10 weeks in Beijing where $PM_{2.5}$ and O_3 concentrations were markedly higher than the pre- and post-travel Los Angeles levels. The authors demonstrated that this travel-related exposure to air pollution induced systemic pro-oxidative and proinflammatory effects, where the biomarkers were interestingly reversed after the participants returned to Los Angeles.[11] The changes in activities of outcome measures (blood biomarkers in particular) in association with exposure to PAH metabolites revealed alteration in oxidative metabolism, which is attributed to ambient air pollution exposure. These changes warrant further studies on biomarkers that can detect early cardiovascular effects due to the air pollution exposure.

In addition to the Lin studies, researchers in Germany investigated nine volunteers who were exposed to higher levels of PM pollution when they travelled from Germany to China by measuring urinary biomarkers.[116] The median concentrations of oxidative stress biomarkers were higher in samples collected after the volunteers returned from China when compared to pre-travel.

Discussion

The main findings of our review reiterate the importance of the exposure to air pollution on health, with the key notable gap being health information and research on the impacts of air pollution exposure on international travellers. To our knowledge, this is the first systematic review that explores the health impacts of air pollution exposure on international travellers. Although limited, the results from the reviewed studies demonstrate that there are associations between exposure to elevated levels of air pollutants and adverse health outcomes in travellers. Therefore, travellers who intend to visit highly polluted cities should take caution by, for example, researching pollution levels in travel cities, avoiding seasons with high pollution levels and wearing masks, as they may experience symptoms or lung function changes, impacting their quality of life and health.

Attention to environmental risks, particularly air pollution in the context of travel, was noted in an early JTM publication by Christopher Sanford (2004).[7] However, based on our findings for this review, very limited work has been done since to assess the CVD and respiratory risks of short-term exposure to higher levels of air pollution during travel. The few studies that researched associations between air pollution exposure concentrations and cardiopulmonary health of travellers support the hypothesis that limited research has been conducted since Sanford called for attention to the potential risks of air pollution to travellers.[10,11,112]

The studies presented evidence of significant lung function decrements from baseline and change in biomarkers related to exposure in healthy young adults. Although the sample sizes were limited, and vulnerable groups were not included, these studies suggest that even short-term exposures to air pollution can result in adverse health effects in healthy young individuals. Based on the studies presented in this review, we can assume that older travellers and those with pre-existing conditions may face higher risk. Further concern for these vulnerable populations arises during travel due to the limited medical facilities for travellers in many of these destinations.

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023

As highlighted in the Introduction, air pollution is higher in megacities and travel destinations in developing countries when compared to developed nations. As discussed, exposure concentration alone should not be a determinant of protection from potential health effects. It is important to note that the toxicity of $PM_{2.5}$ also greatly depends on the composition, which is determined by the sources in a city/region. Therefore, although the $PM_{2.5}$ concentrations may be relatively low in some travel destinations when considering $PM_{2.5}$ mass alone, public health impacts of air pollution and impact on traveller health may be greatly underestimated if the sources and composition are not considered.[68,69,117,118] Another factor to consider when assessing the low concentrations of pollutants in developed cities is the variation of these pollutant concentrations over time. In some cities (e.g. Los Angeles), average $PM_{2.5}$ concentrations meet the annual standards, but maximum concentrations can reach levels above the EPA's 24-h National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ of 35 μg/m^3 during short periods.[69] In essence, travellers need to be aware of the potential for high exposures to pollutants when they travel and recognize that both exposure to the main pollutants and the components are of concern.

The majority of studies highlighted in this review came from East Asian nations, particularly Beijing and Shanghai, where pollutant concentrations are generally high. However, despite having some of the most polluted cities in the world, such as New Delhi, with an exception of one study, there was a notable vacuum in studies assessing the acute CVD and respiratory health effects associated with air pollution exposure in South Asia. Studies are also lacking in South America and Africa. Although cities in Europe and North America may be 'cleaner', it is also important to acknowledge that there could be health concerns when persons travel between these areas. Composition of particulate matter can be different in different countries, which may potentially impact travellers.

In addition to the adverse health risks travellers face due to exposure to air pollutants, travel may be impacted significantly by climate-related events, which are predicted to particularly affect vulnerable urban areas in South Asia, East Asia and the Pacific.[119] Megacities in these regions that are located in low-lying coastal areas are especially vulnerable. Rising global temperatures can increase the frequency of 'extreme events' such as floods, heatwaves, dust storms and wildfires, which can lead to increases in air and water pollution, increased health risks and population displacement in affected regions. Thus, the impact of global warming is expected to contribute to human mobility, leading to increased migration and travel to regions that are perceived to be 'safer'.[120] The implications of global warming on traveller health and climate impacts on the future of the tourism industry should therefore be carefully considered in long-term decisions made by governments and policy makers, warranting further research in this area. Additionally, travellers who plan their trips should be aware of the potential weather extremes that can lead to greater pollution and conversely greater impacts on health.

Although we believe this review provides the most up-to-date knowledge regarding CVD and respiratory health effects of exposure to $PM_{2.5}$ and O_3 in cities abroad during travel, some limitations must be considered. It is possible that there may have been peer-reviewed research that were outside of our search criteria which may provide other health information related to air pollution exposure when travelling abroad. The five longitudinal studies and single case report included in this review were all observational in design. While the improved statistical designs and models used in these studies can control for confounders, factors such as diet, stress during air travel, variations in microenvironments during the stay, the presence of air conditioning, etc. can impact the exposure–health metrics. Therefore, interpretation of these results for the general travel population is challenging and needs further investigation with larger study populations that consider other contributing factors. Additionally, travellers experienced different durations of travel and thus exposure periods, making it hard to compare the outcomes in this review. However, this problem is similar to current air pollution and health research where 'windows of exposure' differ, making the comparison of health outcomes difficult. One of the main limitations of these studies and of air pollution research, in general, is the difficulty in determining the pollutant exposure. Researchers often rely on local monitoring stations or personal monitors for measurement of exposure. Monitoring stations may monitor on different days, for different time periods, and maybe located in varying setting throughout the city or country. Furthermore, the equipment and oversight of these stations vary throughout the world. Personal monitoring is often utilized to determine individual exposures. Although this strategy can provide detailed information about exposure, concerns may be raised about the appropriate use of the monitors. Frequently, these monitors rely on people properly wearing them and then following instructions of protocols. The exposure measurement for studies such as this can be difficult, but all studies from this review provide insight into the need for more research on exposures and health outcomes.

Conclusions

In conclusion, although research provides evidence for differentials in air pollution concentrations between nations and that short-term exposure among city residents is associated with increased CVD and respiratory events, there is a paucity of research on the impact of air pollution on the health of international travellers. The few studies that have been conducted show trends in exposure and adverse health outcomes in international travellers, which beg for more in-depth research. Further studies are warranted to understand the underlying mechanisms and particularly how vulnerable groups are impacted by such exposures when visiting cities abroad.

Supplementary data

Supplementary data are available at *JTM* online.

Authors' contributions

K.M.Z. and M.J.R.V. conceptualized the idea, conducted the systematic review of manuscripts according to the methods presented, wrote the majority of the manuscript and edited all

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023

aspects of the manuscript. A.E.C. merged the data and removed duplicate manuscripts. A.E.C. also participated in the writing of the manuscript and the editing of the manuscript.

Acknowledgements

The authors acknowledge Abigail Christopher, Aakruti Sharma and Jenni Shearston for their help with generating tables and figures.

Funding

None received.

Conflict of Interest

None declared.

References

1. Landrigan PJ, Fuller R, Acosta NJR *et al.* The Lancet Commission on pollution and health. *Lancet* 2018; **391**:462–512.
2. World Health Organization (WHO). *Ambient (Outdoor) Air Pollution*. 2018. https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health. (Accessed date: 20 April 2020)
3. United Nations (UN) Department of Economic and Social Affairs PD. *World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420)*. New York: United Nations, 2019.
4. Molina MJ, Molina LT. Megacities and atmospheric pollution. *J Air Waste Manag Assoc* 2004; **54**:644–80.
5. Geerts W. *Top 100 City Destinations 2018*. Euromonitor International, 2018.
6. World Tourism Organization (UNWTO). *Global and Regional Tourism Performance: Key Tourism Indicators*. 2020. https://www.unwto.org/global-and-regional-tourism-performance (20 August 2020, date last accessed).
7. Sanford C. Urban medicine: threats to health of travelers to developing world cities. *J Travel Med* 2004; **11**:313–27.
8. Gurjar BR, Jain A, Sharma A *et al.* Human health risks in megacities due to air pollution. *Atmos Environ* 2010; **44**:4606–13.
9. World Health Organization (WHO). *WHO Urban Ambient Air Pollution Database*. https://www.who.int/phe/health_topics/outdoorair/databases/AAP_database_summary_results_2016_v02.pdf?ua=1;2016 (Accessed date: 15 July 2020).
10. Vilcassim MJR, Thurston GD, Chen LC *et al.* Exposure to air pollution is associated with adverse cardiopulmonary health effects in international travellers. *J Travel Med* 2019; **26**:taz032.
11. Lin Y, Ramanathan G, Zhu Y *et al.* Pro-oxidative and proinflammatory effects after traveling from Los Angeles to Beijing: a biomarker-based natural experiment. *Circulation* 2019; **140**:1995–2004.
12. Cheng Z, Luo L, Wang S *et al.* Status and characteristics of ambient PM2.5 pollution in global megacities. *Environ Int* 2016; **89–90**:212–21.
13. Xu Q, Wang S, Guo Y *et al.* Acute exposure to fine particulate matter and cardiovascular hospital emergency room visits in Beijing, China. *Environ Pollut* 2017; **220**:317–27.
14. Li M, Wu Y, Tian YH *et al.* Association between PM2.5 and daily hospital admissions for heart failure: a time-series analysis in Beijing. *Int J Environ Res Public Health* 2018; **15**:2217.
15. Yu S, Liu W, Xu Y *et al.* Characteristics and oxidative potential of atmospheric PM2.5 in Beijing: source apportionment and seasonal variation. *Sci Total Environ* 2019; **650**:277–87.
16. Amsalu E, Wang T, Li H *et al.* Acute effects of fine particulate matter (PM2.5) on hospital admissions for cardiovascular disease in Beijing, China: a time-series study. *Environ Health* 2019; **18**:70.
17. Xie W, Li G, Zhao D *et al.* Relationship between fine particulate air pollution and ischaemic heart disease morbidity and mortality. *Heart* 2015; **101**:257–63.
18. Xia R, Zhou G, Zhu T, Li X, Wang G. Ambient air pollution and out-of-hospital cardiac arrest in Beijing, China. *Int J Environ Res Public Health* 2017; **14**:423.
19. Sun XW, Chen PL, Ren L *et al.* The cumulative effect of air pollutants on the acute exacerbation of COPD in Shanghai, China. *Sci Total Environ* 2018; **622–623**:875–81.
20. Wang Y, Shi Z, Shen F *et al.* Associations of daily mortality with short-term exposure to PM2.5 and its constituents in Shanghai, China. *Chemosphere* 2019; **233**:879–87.
21. Liang H, Qiu H, Tian L. Short-term effects of fine particulate matter on acute myocardial infraction mortality and years of life lost: a time series study in Hong Kong. *Sci Total Environ* 2018; **615**:558–63.
22. Tam WWS, Wong TW, Wong AHS. Association between air pollution and daily mortality and hospital admission due to ischaemic heart diseases in Hong Kong. *Atmos Environ* 2015; **120**:360–8.
23. Qiu H, Pun VC, Tian L. Short-term effects of fine and coarse particles on deaths in Hong Kong elderly population: an analysis of mortality displacement. *Environ Pollut* 2018; **241**:148–54.
24. Yorifuji T, Kashima S, Doi H. Associations of acute exposure to fine and coarse particulate matter and mortality among older people in Tokyo, Japan. *Sci Total Environ* 2016; **542**:354–9.
25. Gutierrez-Avila I, Rojas-Bracho L, Riojas-Rodriguez H, Kloog I, Just AC, Rothenberg SJ. Cardiovascular and cerebrovascular mortality associated with acute exposure to PM2.5 in Mexico City. *Stroke* 2018; **49**:1734–6.
26. Wang M, Sampson PD, Sheppard LE, Stein JH, Vedal S, Kaufman JD. Long-term exposure to ambient ozone and progression of subclinical arterial disease: the multi-ethnic study of atherosclerosis and air pollution. *Environ Health Perspect* 2019; **127**:57001.
27. Sun Q, Wang W, Chen C *et al.* Acute effect of multiple ozone metrics on mortality by season in 34 Chinese counties in 2013-2015. *J Intern Med* 2018; **283**:481–8.
28. Belis CA, Larsen BR, Amato F *et al. European Guide on Air Pollution Source Identification with Receptor Models*. European Commission: Publications Office of the European Union, 2014.
29. Thurston GD, Ito K, Lall RA. Source apportionment of U.S. fine particulate matter air pollution. *Atmos Environ (1994)* 2011; **45**:3924–36.
30. Wu S, Yang D, Pan L *et al.* Chemical constituents and sources of ambient particulate air pollution and biomarkers of endothelial function in a panel of healthy adults in Beijing, China. *Sci Total Environ* 2016; **560–561**:141–9.
31. Ostro B, Malig B, Hasheminassab S, Berger K, Chang E, Sioutas C. Associations of source-specific fine particulate matter with emergency department visits in California. *Am J Epidemiol* 2016; **184**:450–9.
32. Halonen JI, Blangiardo M, Toledano MB *et al.* Long-term exposure to traffic pollution and hospital admissions in London. *Environ Pollut* 2016; **208**:48–57.
33. US-EPA. *Criteria Air Pollutants*. 2018. https://www.epa.gov/criteria-air-pollutants#self (25 March 2018, date last accessed).
34. Wheida A, Nasser A, El Nazer M *et al.* Tackling the mortality from long-term exposure to outdoor air pollution in megacities: lessons from the Greater Cairo case study. *Environ Res* 2018; **160**:223–31.

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023

35. Zhou M, He G, Fan M *et al.* Smog episodes, fine particulate pollution and mortality in China. *Environ Res* 2015; **136**:396–404.
36. Wu S, Deng F, Wei H *et al.* Association of cardiopulmonary health effects with source-appointed ambient fine particulate in Beijing, China: a combined analysis from the Healthy Volunteer Natural Relocation (HVNR) study. *Environ Sci Technol* 2014; **48**:3438–48.
37. Chen C, Xu D, He MZ *et al.* Fine particle constituents and mortality: a time-series study in Beijing. *China Environ Sci Technol* 2018; **52**:11378–86.
38. Wang C, Hao L, Liu C *et al.* Associations between fine particulate matter constituents and daily cardiovascular mortality in Shanghai. *China Ecotoxicol Environ Saf* 2020; **191**:110154.
39. Yang Y, Tang R, Qiu H *et al.* Long term exposure to air pollution and mortality in an elderly cohort in Hong Kong. *Environ Int* 2018; **117**:99–106.
40. Maji KJ, Dikshit AK, Deshpande A. Disability-adjusted life years and economic cost assessment of the health effects related to PM2.5 and PM10 pollution in Mumbai and Delhi, in India from 1991 to 2015. *Environ Sci Pollut Res Int* 2017; **24**:4709–30.
41. Times of India. *Top 8 Main Causes for Air Pollution in Delhi*. 2017. https://timesofindia.indiatimes.com/life-style/health-fitness/health-news/top-8-main-causes-for-air-pollution-in-delhi/articleshow/61626744.cms. (Accessed date: 5 March 2020).
42. Mishra M. Poison in the air: declining air quality in India. *Lung India* 2019; **36**:160–1.
43. Chauhan A, Singh RP. Decline in PM2.5 concentrations over major cities around the world associated with COVID-19. *Environ Res* 2020; **187**:109634.
44. Sharma S, Zhang M, Anshika GJ, Zhang H, Kota SH. Effect of restricted emissions during COVID-19 on air quality in India. *Sci Total Environ* 2020; **728**:138878.
45. Srivastava S, Kumar A, Bauddh K, Gautam AS, Kumar S. 21-day lockdown in India dramatically reduced air pollution indices in Lucknow and New Delhi. *India Bull Environ Contam Toxicol* 2020; **105**:9–17.
46. Ma CJ, Kang GU. Air quality variation in Wuhan, Daegu, and Tokyo during the explosive outbreak of COVID-19 and its health effects. *Int J Environ Res Public Health* 2020; **17**:4119.
47. Adhikari A, Yin J. Short-term effects of ambient ozone, PM2.5, and meteorological factors on COVID-19 confirmed cases and deaths in Queens, New York. *Int J Environ Res Public Health* 2020; **17**:4047.
48. Chen K, Wang M, Huang C, Kinney PL, Anastas PT. Air pollution reduction and mortality benefit during the COVID-19 outbreak in China. *Lancet Planet Health* 2020; **4**:e210–2.
49. Li L, Li Q, Huang L *et al.* Air quality changes during the COVID-19 lockdown over the Yangtze River Delta Region: an insight into the impact of human activity pattern changes on air pollution variation. *Sci Total Environ* 2020; **732**:139282.
50. Somani M, Srivastava AN, Gummadivalli SK, Sharma A. Indirect implications of COVID-19 towards sustainable environment: an investigation in Indian context. *Bioresour Technol Rep* 2020; **11**:100491.
51. Le T, Wang Y, Liu L *et al.* Unexpected air pollution with marked emission reductions during the COVID-19 outbreak in China. *Science* 2020; **369**:702–6.
52. Rodriguez-Urrego D, Rodriguez-Urrego L. Air quality during the COVID-19: PM2.5 analysis in the 50 most polluted capital cities in the world. *Environ Pollut* 2020; **266**:115042.
53. Sun Y, Lei L, Zhou W *et al.* A chemical cocktail during the COVID-19 outbreak in Beijing, China: insights from six-year aerosol particle composition measurements during the Chinese New Year holiday. *Sci Total Environ* 2020; **742**:140739.
54. World Health Organization (WHO). *Cardiovascular Diseases (CVDs)*. 2017. https://wwwwhoint/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds). (Accessed date: 2 February 2020).
55. Li G, Lan H, Liu Z *et al.* The association between short-term exposure to fine particulate matter and outpatient visit in Beijing, China. *Iran J Public Health* 2017; **46**:1486–94.
56. Ma Y, Yang S, Yu Z, Jiao H, Zhang Y, Ma B. A study on the short-term impact of fine particulate matter pollution on the incidence of cardiovascular diseases in Beijing, China. *Atmos Environ* 2019; **215**:116889.
57. Feng B, Song X, Dan M *et al.* High level of source-specific particulate matter air pollution associated with cardiac arrhythmias. *Sci Total Environ* 2019; **657**:1285–93.
58. Ye X, Peng L, Kan H *et al.* Acute effects of particulate air pollution on the incidence of coronary heart disease in Shanghai, China. *PLoS One* 2016; **11**:e0151119.
59. Qiu H, Yu IT-s, Wang X, Tian L, Tse LA, Wong TW. Differential effects of fine and coarse particles on daily emergency cardiovascular hospitalizations in Hong Kong. *Atmos Environ* 2013; **64**:296–302.
60. Shi J, Chen R, Yang C *et al.* Association between fine particulate matter chemical constituents and airway inflammation: a panel study among healthy adults in China. *Environ Res* 2016; **150**:264–8.
61. Xie Y, Bo L, Jiang S *et al.* Individual PM2.5 exposure is associated with the impairment of cardiac autonomic modulation in general residents. *Environ Sci Pollut Res Int* 2016; **23**:10255–61.
62. Geng F, Hua J, Mu Z *et al.* Differentiating the associations of black carbon and fine particle with daily mortality in a Chinese city. *Environ Res* 2013; **120**:27–32.
63. Liu X, Kong D, Liu Y *et al.* Effects of the short-term exposure to ambient air pollution on atrial fibrillation. *Pacing Clin Electrophysiol* 2018; **41**:1441–6.
64. Su C, Breitner S, Schneider A *et al.* Short-term effects of fine particulate air pollution on cardiovascular hospital emergency room visits: a time-series study in Beijing. *China Int Arch Occup Environ Health* 2016; **89**:641–57.
65. Xu A, Mu Z, Jiang B *et al.* Acute effects of particulate air pollution on ischemic heart disease hospitalizations in Shanghai, China. *Int J Environ Res Public Health* 2017; **14**:168.
66. Silverman RA, Ito K, Freese J *et al.* Association of ambient fine particles with out-of-hospital cardiac arrests in New York City. *Am J Epidemiol* 2010; **172**:917–23.
67. Wu Y, Li M, Tian Y *et al.* Short-term effects of ambient fine particulate air pollution on inpatient visits for myocardial infarction in Beijing. *China Environ Sci Pollut Res Int* 2019; **26**: 14178–83.
68. Lall R, Ito K, Thurston GD. Distributed lag analyses of daily hospital admissions and source-apportioned fine particle air pollution. *Environ Health Perspect* 2011; **119**:455–60.
69. Zhang X, Staimer N, Tjoa T *et al.* Associations between microvascular function and short-term exposure to traffic-related air pollution and particulate matter oxidative potential. *Environ Health* 2016; **15**:81.
70. Haley VB, Talbot TO, Felton HD. Surveillance of the short-term impact of fine particle air pollution on cardiovascular disease hospitalizations in New York State. *Environ Health* 2009; **8**:42.
71. Hsu WH, Hwang SA, Kinney PL, Lin S. Seasonal and temperature modifications of the association between fine particulate air pollution and cardiovascular hospitalization in New York state. *Sci Total Environ* 2017; **578**:626–32.
72. Luo K, Li W, Zhang R, Li R, Xu Q, Cao Y. Ambient fine particulate matter exposure and risk of cardiovascular mortality: adjustment of

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023

the meteorological factors. *Int J Environ Res Public Health* 2016; **13**:1082.

73. Gong T, Sun Z, Zhang X *et al.* Associations of black carbon and PM2.5 with daily cardiovascular mortality in Beijing, China. *Atmos Environ* 2019; **214**:116876.
74. Kan H, Chen B, Zhao N *et al.* Part 1. A time-series study of ambient air pollution and daily mortality in Shanghai, China. *Res Rep Health Eff Inst* 2010; **154**:17–78.
75. Li P, Xin J, Wang Y *et al.* Time-series analysis of mortality effects from airborne particulate matter size fractions in Beijing. *Atmos Environ* 2013; **81**:253–62.
76. Larrieu S, Jusot JF, Blanchard M *et al.* Short term effects of air pollution on hospitalizations for cardiovascular diseases in eight French cities: the PSAS program. *Sci Total Environ* 2007; **387**:105–12.
77. Hoi K-I, Zhang D-B, Mok K-M, Yuen K-V. Association of human mortality with air pollution of Hong Kong. *Toxics* 2014; **2**:158–164.
78. Romieu I, Gouveia N, Cifuentes LA *et al.* Multicity study of air pollution and mortality in Latin America (the ESCALA study). *Res Rep Health Eff Inst* 2012; **171**:5–86.
79. Wong TW, Tam WS, Yu TS, Wong AH. Associations between daily mortalities from respiratory and cardiovascular diseases and air pollution in Hong Kong. *China Occup Environ Med* 2002; **59**:30–5.
80. Bremner SA, Anderson HR, Atkinson RW *et al.* Short-term associations between outdoor air pollution and mortality in London 1992-4. *Occup Environ Med* 1999; **56**:237–44.
81. Forum of International Respiratory Societies. *The Global Impact of Respiratory Disease*, 2nd edn. Paris: Sheffield European Respiratory Society, 2017.
82. World Health Organization (WHO). *The Top 10 Causes of Death*. 2019. https://wwwwhoint/news-room/fact-sheets/detail/the-top-10-causes-of-death. (Accessed date: 10 February 2020).
83. Gao N, Li C, Ji J *et al.* Short-term effects of ambient air pollution on chronic obstructive pulmonary disease admissions in Beijing, China (2013-2017). *Int J Chron Obstruct Pulmon Dis* 2019; **14**: 297–309.
84. Ni Y, Wu S, Ji W *et al.* The exposure metric choices have significant impact on the association between short-term exposure to outdoor particulate matter and changes in lung function: findings from a panel study in chronic obstructive pulmonary disease patients. *Sci Total Environ* 2016; **542**:264–70.
85. Tian Y, Xiang X, Juan J *et al.* Short-term effects of ambient fine particulate matter pollution on hospital visits for chronic obstructive pulmonary disease in Beijing. *China Environ Health* 2018; **17**:21.
86. Silverman RA, Ito K. Age-related association of fine particles and ozone with severe acute asthma in New York City. *J Allergy Clin Immunol* 2010; **125**:367–73.
87. Liang L, Cai Y, Barratt B *et al.* Associations between daily air quality and hospitalisations for acute exacerbation of chronic obstructive pulmonary disease in Beijing, 2013-17: an ecological analysis. *Lancet Planet Health* 2019; **3**:e270–9.
88. Ko FW, Tam W, Wong TW *et al.* Effects of air pollution on asthma hospitalization rates in different age groups in Hong Kong. *Clin Exp Allergy* 2007; **37**:1312–9.
89. Bi J, D'Souza RR, Rich DQ *et al.* Temporal changes in short-term associations between cardiorespiratory emergency department visits and PM2.5 in Los Angeles, 2005 to 2016. *Environ Res* 2020; **190**:109967.
90. Li T, Yan M, Sun Q, Anderson GB. Mortality risks from a spectrum of causes associated with wide-ranging exposure to fine particulate matter: a case-crossover study in Beijing, China. *Environ Int* 2018; **111**:52–9.
91. Dai Y, Qiu H, Sun S, Yang Y, Lin H, Tian L. Age-dependent effect of ambient ozone on emergency asthma hospitalizations in Hong Kong. *J Allergy Clin Immunol* 2018; **141**:1532–4.
92. Qiu H, Yu IT-s, Wang X, Tian L, Tse LA, Wong TW. Cool and dry weather enhances the effects of air pollution on emergency IHD hospital admissions. *Int J Cardiol* 2013; **168**:500–5.
93. Yoda Y, Otani N, Sakurai S, Shima M. Acute effects of summer air pollution on pulmonary function and airway inflammation in healthy young women. *J Epidemiol* 2014; **24**:312–20.
94. Pun VC, Ho KF. Blood pressure and pulmonary health effects of ozone and black carbon exposure in young adult runners. *Sci Total Environ* 2019; **657**:1–6.
95. Li H, Wu S, Pan L *et al.* Short-term effects of various ozone metrics on cardiopulmonary function in chronic obstructive pulmonary disease patients: results from a panel study in Beijing, China. *Environ Pollut* 2018; **232**:358–66.
96. Sunyer J, Spix C, Quenel P *et al.* Urban air pollution and emergency admissions for asthma in four European cities: the APHEA Project. *Thorax* 1997; **52**:760–5.
97. Wong TW, Lau TS, Yu TS *et al.* Air pollution and hospital admissions for respiratory and cardiovascular diseases in Hong Kong. *Occup Environ Med* 1999; **56**:679–83.
98. Anderson HR, Ponce de Leon A, Bland JM, Bower JS, Emberlin J, Strachan DP. Air pollution, pollens, and daily admissions for asthma in London 1987-92. *Thorax* 1998; **53**:842–8.
99. Atkinson RW, Anderson HR, Strachan DP, Bland JM, Bremner SA, Ponce de Leon A. Short-term associations between outdoor air pollution and visits to accident and emergency departments in London for respiratory complaints. *Eur Respir J* 1999; **13**:257–65.
100. Qiu H, Yu ITS, Wang X, Tian L, Tse LA, Wong TW. Season and humidity dependence of the effects of air pollution on COPD hospitalizations in Hong Kong. *Atmos Environ* 2013; **76**:74–80.
101. Landguth EL, Holden ZA, Graham J *et al.* The delayed effect of wildfire season particulate matter on subsequent influenza season in a mountain west region of the USA. *Environ Int* 2020; **139**:105668.
102. Cui Y, Zhang ZF, Froines J *et al.* Air pollution and case fatality of SARS in the People's Republic of China: an ecologic study. *Environ Health* 2003; **2**:15.
103. Bashir MF, Ma B, Bilal *et al.* Correlation between climate indicators and COVID-19 pandemic in New York, USA. *Sci Total Environ* 2020; **728**:138835.
104. Bashir MF, Ma BJ, Bilal *et al.* Correlation between environmental pollution indicators and COVID-19 pandemic: a brief study in Californian context. *Environ Res* 2020; **187**:109652.
105. Li H, Xu XL, Dai DW, Huang ZY, Ma Z, Guan YJ. Air pollution and temperature are associated with increased COVID-19 incidence: a time series study. *Int J Infect Dis* 2020; **97**:278–82.
106. Sasidharan M, Singh A, Torbaghan ME, Parlikad AK. A vulnerability-based approach to human-mobility reduction for countering COVID-19 transmission in London while considering local air quality. *Sci Total Environ* 2020; **741**:140515.
107. Yao Y, Pan J, Wang W *et al.* Association of particulate matter pollution and case fatality rate of COVID-19 in 49 Chinese cities. *Sci Total Environ* 2020; **741**:140396.
108. Zhang Z, Xue T, Jin X. Effects of meteorological conditions and air pollution on COVID-19 transmission: evidence from 219 Chinese cities. *Sci Total Environ* 2020; **741**:140244.
109. Zhu Y, Xie J, Huang F, Cao L. Association between short-term exposure to air pollution and COVID-19 infection: evidence from China. *Sci Total Environ* 2020; **727**:138704.
110. Frontera A, Cianfanelli L, Vlachos K, Landoni G, Cremona G. Severe air pollution links to higher mortality in COVID-19 patients: the "double-hit" hypothesis. *J Infect* 2020; **81**:255–9.

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023

111. Liang D, Shi L, Zhao J *et al.* Urban air pollution may enhance COVID-19 case-fatality and mortality rates in the United States. *Innovation (N Y)* 2020; **1**:100047.
112. Vilcassim MJR, Gordon T, Sanford CA. Does air pollution contribute to travelers' illness and deaths?-evidence from a case report and need for further studies. *J Travel Med* 2018; **25**:tay002.
113. Thurston GD, Kipen H, Annesi-Maesano I *et al.* A joint ERS/ATS policy statement: what constitutes an adverse health effect of air pollution? An analytical framework. *Eur Respir J* 2017; **49**:1600419.
114. Sato R, Gui P, Ito K, Kohzuki M, Ebihara S. Effect of short-term exposure to high particulate levels on cough reflex sensitivity in healthy tourists: a pilot study. *Open Respir Med J* 2016; **10**:96–104.
115. Lin Y, Qiu X, Yu N, Yang Q, Araujo JA, Zhu Y. Urinary metabolites of polycyclic aromatic hydrocarbons and the association with lipid peroxidation: a biomarker-based study between Los Angeles and Beijing. *Environ Sci Technol* 2016; **50**:3738–45.
116. Wu X, Lintelmann J, Klingbeil S *et al.* Determination of air pollution-related biomarkers of exposure in urine of travellers between Germany and China using liquid chromatographic and liquid chromatographic-mass spectrometric methods: a pilot study. *Biomarkers* 2017; **22**:525–36.
117. Ito K, Mathes R, Ross Z, Nadas A, Thurston G, Matte T. Fine particulate matter constituents associated with cardiovascular hospitalizations and mortality in New York City. *Environ Health Perspect* 2011; **119**:467–73.
118. Fecht D, Hansell AL, Morley D *et al.* Spatial and temporal associations of road traffic noise and air pollution in London: implications for epidemiological studies. *Environ Int* 2016; **88**:235–42.
119. Schwerdtle PN, Bowen K, McMichael C, Sauerborn R. Human mobility and health in a warming world. *J Travel Med* 2019; **26**:tay160.
120. Semenza JC, Ebi KL. Climate change impact on migration, travel, travel destinations and the tourism industry. *J Travel Med* 2019; **26**:taz026.

Downloaded from https://academic.oup.com/jtm/article/28/4/taab055/6210993 by guest on 06 September 2023