EUROPEAN RESPIRATORY *journal*

FLAGSHIP SCIENTIFIC JOURNAL OF ERS

Early View

State of the Art

Personal strategies to minimise effects of air pollution on respiratory health: advice for providers, patients and the public

Christopher Carlsten, Sundeep Salvi, Gary W.K. Wong, Kian Fan Chung

Please cite this article as: Carlsten C, Salvi S, Wong GWK, *et al*. Personal strategies to minimise effects of air pollution on respiratory health: advice for providers, patients and the public. *Eur Respir J* 2020; in press (https://doi.org/10.1183/13993003.02056-2019).

This manuscript has recently been accepted for publication in the *European Respiratory Journal*. It is published here in its accepted form prior to copyediting and typesetting by our production team. After these production processes are complete and the authors have approved the resulting proofs, the article will move to the latest issue of the ERJ online.

Personal strategies to minimise effects of air pollution on respiratory health: advice for providers, patients and the public

Christopher Carlsten MD[1], Sundeep Salvi PhD[2], Gary WK Wong MD[3], Kian Fan Chung MD[4]

1. Air Pollution Exposure Laboratory, Department of Medicine, University of British Columbia, Vancouver, Canada

2. Chest Research Foundation, Pune, India

3. Department of Pediatrics and School of Public Health, Chinese University of Hong Kong, Shatin, Hong Kong

4. Faculty of Medicine, National Heart and Lung Institute, Imperial College London, and Royal Brompton & Harefield NHS Foundation Trust, London, UK

Correspondence to:

Professor C Carlsten

Department of Medicine,

University of British Columbia,

Vancouver,

Canada

Email: christopher.carlsten@ubc.ca

Telephone: 604 839 1561

Authors' contributions

The authors were fully responsible for all content and editorial decisions, were involved at all stages of manuscript development and have approved the final version.

This article has an online supplement.

Take home message:

The article draws on published literature and evidence to provide clear guidance on personal strategies that can help providers, patients, and the public minimise daily exposure to air pollution in order to benefit respiratory health.

Abstract

As global awareness of air pollution rises, so does the imperative to provide evidence-based recommendations for strategies to mitigate its impact. While public policy has a central role in reducing air pollution, exposure can also be reduced by personal choices. Qualified evidence supports limiting physical exertion outdoors on high air pollution days and near air pollution sources, reducing near-roadway exposure while commuting, utilising air quality alert systems to plan activities, and wearing facemasks in prescribed circumstances. Other strategies include avoiding cooking with solid fuels, ventilating and isolating cooking areas, and using portable air cleaners fitted with high efficiency particulate air filters. We detail recommendations to assist providers and public health officials when advising patients and the public regarding personal-level strategies to mitigate risk imposed by air pollution, while recognising that well-designed prospective studies are urgently needed to better establish and validate interventions that benefit respiratory health in this context.

Introduction

Air pollution (AP) and climate change were recognised as the top environmental global threats to human health in 2019 by the World Health Organization (WHO) [1]. A recent refined modelling indicates that prior prediction models have underestimated the health burden of AP and estimate there are currently ~9 million annual deaths from global AP [2] with >99% of deaths due to household AP, and nearly 90% of deaths due to ambient AP occurring in low- and middle-income countries [3] where burning of solid fuels for cooking and heating is a major health concern [4]. Over 25% of premature deaths associated with AP were reported to be respiratory in nature [5], and we focus this review on respiratory health, knowing that minimising airway exposure generally protects also against cardiovascular effects [6-8] (given that inhalation is the common portal of entry). Since there is no known level of AP exposure that is risk-free, strategies to minimise daily exposure can be impactful across a wide range of settings and the nonlinear nature of the exposure–response curves for many health outcomes implies that the greatest benefits may occur when relatively low AP exposure levels are reduced even further [2, 9].

Urban planning must evolve so that concerns regarding air pollution become central to development (rather than an afterthought) and city centres must become practically designed so as to make living and working in close proximity attractive. This will avoid sprawl and make active transport more realistic. Such planning is critical. Other aspects of public policy play a primary role in source control and structural approaches to minimise exposure, and individuals should act as broadly as possible to reduce the root causes of fossil-fuel dependence (through consumer choice, participation in the democratic process, or other advocacy). Still, the impact of AP can also be reduced by personal choices. Therefore, the public must be empowered with strategies to minimise the effects of AP on respiratory health, but there remains an unmet need in providing education and support to communities around ways in which they can limit their exposure to the harmful levels of AP [10]. A report in 2016 by the Royal College of Physicians in the UK recommended that healthcare professionals (HCPs) should help vulnerable patients protect themselves from the effects of

AP [11], and yet a subsequent workshop convened by the European Respiratory Society highlighted the lack of evidence-based tools available in this regard [10].

Accordingly, HCPs should be armed with up-to-date scientific evidence in order to prescribe impact-reducing tactics. This will allow HCPs to leverage their position as trusted messengers and embrace their responsibility to educate and advocate for preventive measures rather than simply reactive treatment. Our aim, therefore, is to provide recommendations for individuals to minimise their personal exposure to AP with advice that can be adapted to local needs in different countries, particularly when relevant to those who suffer from respiratory conditions, such as asthma and chronic obstructive pulmonary disease (COPD), or are at risk for these conditions. We designed a search strategy to uncover evidence surrounding ten key approaches for reduction of outdoor or indoor AP exposure, after which we detailed and finally summarised that evidence for the reader.

Search strategy and selection criteria

PubMed and Google Scholar were searched from 01 January 2013 to 01 January 2019 for search terms relating to AP, respiratory health, and strategies to minimise exposure to AP from ambient and household sources. The full list of the search terms and the resulting 'hits' can be found in Supplementary Table 1 in the online supplement. The flow chart of the literature review is shown in Figure 1. Using that approach, we identified peer-reviewed scientific evidence that addressed the effectiveness of personal-level interventions to reduce exposure to AP, as well as the role therein of effect modifiers such as diet and lifestyle. Additionally, key knowledge gaps and research directions were identified to help clarify current uncertainties relating to AP exposure and health outcomes. The literature search was restricted to the last 6 years in order to build on previous expert reviews and focus on the most up-to-date evidence. In order to assess the strength of the evidence, a level-of-evidence score was assigned to include clinical studies based on the grading used in the Global Initiative for Asthma (GINA) [12] (see Supplementary Table 2 in the online supplement), inclusive of those scenarios in which recommendations are driven primarily by expert opinion rather than strong primary evidence.

Minimising personal exposure to ambient AP

1. Use facemasks under appropriate circumstances [Evidence grade C]

Recommendations

- When anticipating unavoidable exposure to ambient AP exceeding recommended levels, consider close-fitting N95 facemasks after becoming informed about their limitations and pitfalls.
- When using a facemask, follow manufacturers' guidance on correct mask usage, maintenance and fit, including a user seal check [13].
- People with chronic respiratory, cardiac, or other conditions that make breathing difficult should check with their healthcare provider before using an N95 facemask [14].

Background and evidence

Use of filtering facemasks to reduce inhalation of high AP levels is becoming more commonplace and socially acceptable around the world, particularly in Asia [15] but effectiveness varies according to the type of mask and filter, type of pollutant, and conditions of use [16]. Furthermore, filters are designed to remove particles and require additional absorbing features such as activated charcoal to efficiently remove gases [13, 16, 17], which are inconsistently effective and come at an increased cost.

Mask effectiveness is related to filter quality and coverage, number of different filter layers, how well the mask fits to the face and the size of incoming particles (N95 effectiveness drops considerably within the ultrafine range) [18]. Facial hair [14], facial structure, and movement have a large impact on the actual protection conferred, even if the laboratory-based filtration efficacy is high [19]. To measure the effectiveness of facemasks, a study in Beijing measured the amount of black carbon (BC) inside a mask, expressed as a percentage of the BC concentration outside of the mask (in an exposure chamber) to determine the average total inward leakage of BC; this ranged from 3−68% dependent on mask design and fit [19]. Furthermore, user comfort and acceptability are important for mask effectiveness [16], but are not routinely tested or uniformly certified in the consumer context. Users who, based on age [14] or ethnicity [20], are outside of the typical testing prototype may have particular challenges.

Masks can trap warm, moist air, leading to rashes or overheating [21], and potentially pathogen retention [22]. Additionally, respirators may increase resistance to breathing, which may contribute to potential cardiovascular effects [16, 23, 24]. Cloth masks, which are inexpensive and used commonly in underdeveloped regions, remove only 15% of particles of size typical of diesel engine emissions [25] and are far inferior to protection against fine particles than facemasks rated as N95 [13, 25], (defined as filtering ≥95% of 0.3 μm particles under test conditions) [14].

Disposable surgical masks appear more effective than cloth or ‘bandana-style’ masks [26, 27]. However, the design of surgical masks confers poor facial fit [14] and often high inward leakage during actual use [19]. Facemasks may even confer on users a false sense of security and an assumption of protection that can detract from primary AP avoidance efforts [25].

Evidence that N95 facemask use has an impact on cardiopulmonary health is limited. Short-term (2-hour) use reduced particle-associated airway inflammation [24] and improved measures of autonomic nervous function [8, 28], and blood pressure [8] versus wearing no facemask. N95 facemask use reduced the decline in lung function associated with AP among traffic police in Nepal [27]. In a small, randomised, crossover study, powered-air-purifying respirators with high efficiency particulate air (HEPA) filters (likely impractical for most users) reduced exhaled markers of oxidative stress in individuals in cars within heavy traffic versus without HEPA filters [29], although another study using a standard N95 facemask showed no protection from systemic oxidative stress [24].

With technical improvements (e.g., using nanofiber technologies, metal-organic coatings and anti-microbial features, and the use of 3D-printing for better fitting personal facemasks), facemasks may provide better filtration and comfort [30-33]. However, each such innovation requires rigorous testing to ensure effectiveness.

2. Shift from motorised to active transport whenever possible [Evidence grade C]

Recommendations

- A shift from motorised to active transport (cycling or walking) should be encouraged.
- Infrastructure should be designed to prioritise active transportation and make age-appropriate accommodations.

Background and evidence

High exposures to traffic-related AP (TRAP) can occur inside vehicles due to the proximity of air intake of exhaust emissions from neighbouring vehicles as well as while walking or cycling alongside roads [34]. Comparing AP exposures related to active versus motorised travel modes found the highest exposures for air pollutants such as particulate matter (PM) with an aerodynamic diameter <2.5 µm ($PM_{2.5}$), BC, and ultrafine particles (UFP) were in car drivers with the lowest in cyclists or pedestrians [35, 36], although other studies have reported conflicting results [37−39]. Proximity to motorised traffic was associated with high cyclist and pedestrian exposure concentrations [40, 41], particularly when cycling along roads shared with motor vehicles [37, 42].

Cyclists, followed by pedestrians, have the highest level of inhalation and uptake dose of air pollutants (owing to their close proximity to traffic, increased respiration rates, and longer journeys) while the lowest are by train, metro and subway commuters, and motorcyclists [43-45]. However, the benefits of physical activity when actively commuting versus using motorised transport appear to outweigh the risks associated with the increased inhaled dose of air pollutants [43, 46-48], and a protective effect of physical activity with respect to mortality even in high AP environments has been reported [49, 50].

Walking along a traffic-polluted road curtails or even reverses the cardiorespiratory benefits of exercise in older individuals and in adults with chronic cardiorespiratory disorders [51]. However, older people may be more vulnerable to traffic incidents while walking or cycling than younger people [47].

A shift from car and public transport use to active transport (cycling or walking) has been advocated [52, 53] with benefits derived from a reduction in traffic volume and related AP emissions leading to overall health benefits [54] in spite of minor reductions in lung function in some contexts [55].

3. Choose travel routes that minimise near-road AP exposure [Evidence grade C]

Recommendations

- Avoid major intersections, queuing traffic, heavily trafficked roads, and higher-emission sides of a given road.
- Select routes with open spaces and/or greater heterogeneity in building morphology to facilitate dispersal of air pollutants.
- Use designated off-road cycle tracks versus on-road bicycle paths.
- Use up-to-date real-time information on local air quality, such as mobile phone applications, news feeds, and websites to guide route and timing.

Background and evidence

TRAP levels decline steeply with increasing distance from motorised vehicles [16, 41], with up to ten-times lower concentrations of BC when 10 metres away from traffic roads [56]. Therefore, increasing the distance between pedestrians and cyclists from vehicle emissions is a fundamental aim. Even crossing to the less polluted side of a given same road can lead to a reduction of 18% of exposure to $PM_{2.5}$ [57, 58].

The highest particle number concentrations (PNCs) are found at the most congested and highly built-up parts of a route such as at traffic intersections [59], with levels 29-times higher than those found during free-flowing traffic conditions [60]. Pedestrian and cyclist exposure at traffic intersections was higher than on roads with free-flowing traffic [56, 61, 62]. Repeated vehicle accelerations and decelerations at intersections also increases in-vehicle TRAP exposure [63]. In contrast, roads in urban areas with open space and heterogeneous building morphology had around two to three-fold lower concentrations of traffic emissions [61]. Therefore, choice of commuting routes and shifting active travel by cycling from a high-traffic road to an adjacent low-traffic road would lead to lesser exposure [41, 61, 62, 64, 65].

Bike paths or routes separated from motor traffic lanes had lower levels of air pollutants [66, 67]. The use of designated off-road cycle tracks versus on-road bicycle paths reduced cyclist exposure to air pollutants [43, 67-69], and use of sidewalks and off-road bicycle lanes separated by 7 and 19 metres from the roadways resulted in significantly lower exposure than on the road [69]. The use of designated off-road footpath and cycle tracks may be considered in community-level interventions (Figure 2). Many of these routes may be associated with green space, which appears to provide mental health, metabolomic and cardiovascular benefit but may unfortunately confer risk to respiratory health [73].

Children are, by their shorter stature, closer to the source of AP and have a faster respiratory rate which results in their exposure to BC being disproportionately high, particularly in association with transit to and from school, and at school [74]. Children's exposure can be reduced by avoiding major intersections, busy roads, and queuing traffic where possible, and walking on the least trafficked side of the road [58]. Walking on the downhill side of the road (relative to traffic flow) may also help since driving uphill induces engine load, which increases emissions [75].

4. Optimise driving style and vehicle settings [Evidence grade D]

Recommendations

- Optimise and maintain vehicle filtration/ventilation and, when in conditions of high AP, drive with windows closed and keep the air on internal circulation.
- Avoid rapid accelerations and decelerations, restrict engine idling and correctly maintain vehicles.

Background and evidence

As a society, we should promote incentives to move away from fossil fuel combustion, support alternative energy sources and associated infrastructure such as charging stations, and encourage development of non-polluting materials for brakes and tires. However, individuals who use personal vehicles for travel (even if they themselves use vehicles with non-combusting technology, such as electric vehicles) are exposed to levels of AP dependent on ventilation parameters, the ventilation system, and natural leakage from door seals and window cracks of the vehicle [16]. Car-cabin pollutant levels are similar to outdoor concentrations of PM and carbon monoxide (CO) levels when windows are open [76]. While in traffic, opening car windows increased in-car cabin BC and UFP concentrations by two to four-fold versus driving with windows closed [40, 77, 78] and in buses, by three-fold [79]. Driving with windows closed was found to reduce traffic-related $PM_{2.5}$ exposure by around three-fold versus windows open [37].

Physical barriers like controlled ventilation settings in cars help to extract and filter fine and coarse particles from the vehicle microenvironment [43]. Driving personal vehicles with windows closed and with air conditioning set to the ‘recirculate’ setting reduced in-vehicle particle concentrations by up to 75% versus driving with open windows [68], and $PM_{2.5}$ exposure levels were reduced by ~40% [80]. Using a fan set to recirculation versus external circulation mode while in traffic reduces TRAP exposures [76, 81], with one study showing UFP exposure reduction of up to 20% by recirculation through a HEPA filter [82].

Driving patterns such as frequent accelerations and idling influence vehicles emissions [76]. Frequent idling of vehicles was associated with high pollutant exposure for commuters using ground motorised transport on over-congested routes [43], while increasing levels of outdoor air pollutants [83], increasing in-vehicle exposures to air pollutants such as UFP and BC [84], and increasing in-car volatile organic compound concentrations 1.3−5.0-fold compared with when the engine was off [85]. Idling prohibition or anti-idling campaigns near schools have shown significant reduction in PM and harmful pollutants around schools [83, 86].

Older vehicles tend to generate higher emissions due to deterioration of vehicle control systems [87], incomplete combustion of fuel and oil, abrasion and wear of tires and metallic components [88], and more permissive emission standards than newer vehicles.

5. Moderate outdoor physical activity when and where AP levels are high [Evidence grade C]

Recommendations

- Regular physical activity is generally beneficial except in conditions of extreme AP (especially for those with significant susceptibility such as cardiopulmonary disease).

- When exercising, do so away from traffic whenever possible, follow local air quality forecasts and plan outdoor activities around them.
- Decrease or stop exercising when noticing concerning symptoms such as coughing, chest tightness, or wheezing.

Background and evidence

Outdoor activity and exercise could increase the impact of AP on respiratory health due to increased inhaled dose of air pollutants and to bypassing the nasal filtration defences [89]. Strenuous exercise may impair nasal mucociliary clearance and reduce nasal cilia beat frequency, leading to an increase in AP exposure [89], which can contribute to respiratory symptoms such as coughing, wheezing, and breathlessness [90].

Still, physical activity might protect against the negative effects of TRAP on lung function in healthy adults [91-93]. One study suggested a threshold to negative effects on lung function at modest PM levels [94]. However, intermittent moderate physical activity increased pulmonary function at low ($PM_{2.5}$ 30 µg m^{-3}) and high ($PM_{2.5}$ 81 µg m^{-3}) TRAP levels [91], and the adverse effects on lung function markers were negated by physical activity at low ($PM_{2.5}$ 39 µg m^{-3}) and high ($PM_{2.5}$ 82 µg m^{-3}) TRAP levels [93].

Overall, the optimal level of physical activity or threshold at which it can be protective against AP-related health risks is not known and likely to vary across age and health/disease status [89], and individuals with pre-existing conditions, and children are particularly sensitive to AP exposure [89]. Older adults with COPD who walked on a traffic-polluted road in London for 2 hours were found to have more cough, sputum, shortness of breath, and wheeze versus walking in a traffic-free area [51]. Attenuation of the beneficial effects of physical activity on respiratory/pulmonary measures in healthy adults and those with chronic cardiorespiratory disorders when exposed to high versus low AP concentrations was noted [51]. The negative effect of $PM_{2.5}$ on lung function was greater among Korean adults with suspected COPD or asthma who did not exercise versus those that did [95]. Regular exercise was associated with lower markers of systemic inflammation (white blood cell counts) than inactivity at different levels of $PM_{2.5}$ exposure in Taiwan [96]. The beneficial health effects of regular physical activity on overall mortality were not moderated by long-term exposure to urban levels of AP, although cycling in areas with high AP versus moderate or low levels reduced the benefits of physical activity on respiratory mortality [49]. Increased exposure to nitrogen dioxide (NO_2) did not outweigh the beneficial effects of exercise for reducing risk of hospitalisation for asthma and COPD [97]. Therefore, even patients with pre-existing cardiorespiratory disease may experience neutral or beneficial effects of physical activities outdoor, including during periods of elevated AP, but may need to decrease intensity of exertion in proportion to severity of AP levels.

Those at risk can reduce their exposure to air pollutants by staying indoors on high pollution days and limiting outdoor physical activity near sources of AP [16, 89, 90, 98], consistent with recommended World Air Quality Index (AQI) value actions [99], and US Environmental Protection Agency (EPA) standard [100] (see Supplementary Figure 1 in the online supplement).

In the US, AP was associated with reduced leisure-time physical activity and increased risk for physical inactivity [101, 102], as well as a self-reported reduction in outdoor activities [103]. In China, participation in outdoor exercise was impeded by AP severity [104], although better AQI levels and lower concentrations of fine PM were associated with approximately a 20- and 45-minute reduction in sedentary time, respectively [105].

To minimise the respiratory health effects of AP, local governments often issue alerts on days when AP levels are forecast to be high, urging individuals at risk to stay indoors on such days. There is evidence to suggest that some people modify their outdoor activity when alerts are issued, especially those individuals with known susceptibility [16, 106, 107], and this seems reasonable as a matter of caution (particularly when curtailing activity is only temporary, so that the long-term benefits of exercise are not lost).

6. Monitor AP levels [Evidence grade D]

Recommendations

- HCPs should encourage patients to be aware of the local air quality and teach them how to check the air quality forecast and act to minimise AP exposure.
- Patients, especially those with underlying susceptibility, should be aware of air quality alerts and learn to implement appropriate protective behaviour on high AP days.
- If using a personal pollution monitor, users need to be aware that accuracy of such monitors is highly variable and that government-sponsored pollution monitors remain the standard for accuracy.

Background and evidence

AP monitoring networks around the world that report real-time, local levels of ambient AP can provide information on when and where air pollutant levels are elevated above levels thought to confer increased risk [16]. For easy understanding by the general public, most authorities convert increasing concentrations of major air pollutants ($PM_{2.5}$, particulate matter with an aerodynamic diameter <10 µm [PM_{10}], ozone [O_3], CO, NO_2, and sulphur dioxide [SO_2]) into a single value indicating the relative quality of the ambient air and use severity bands to indicate progressive degrees of risk to health [108] as exemplified by the US EPA and World AQI scales (see Supplementary Figure 1 in the online supplement) [99, 100].

AQI scales may not be directly comparable between countries [108] due to differing air quality standards and use of different air pollutant cut-offs to define the severity bands [109-111]. Many AQIs calculate air quality according to the concentration of the highest individual pollutant at that time [112], not recognising the combined impacts of multiple pollutants, and thus may underestimate the associated health risks [109, 111, 113].

Air quality health indices (AQHIs) use the relative health risks of a combination of pollutants to determine the final index [109, 112, 113]. An AQHI based on the short-term associations of SO_2, NO_2, O_3, and $PM_{2.5}$ with mortality in China demonstrated greater correlation with health effects than current AQI systems [113]. When compared with AQHIs, the US EPA AQI underestimated the health effects of AP on high-pollution days in China by at least one category of severity [109].

Regardless, AQIs may enhance public awareness of AP levels and encourage protective behaviours during periods of high AP [109, 110, 112, 113], particularly among high-risk individuals [111]. Real-time maps can provide the short-term health risk based on current pollution levels, and some AQIs provide automated alerts to limit prolonged or heavy exertion outdoors when AP levels are high [114]. AQIs can be used to generate longer term ‘risk maps’ to estimate patients’ chronic AP exposure at their homes and workplaces [115] and can help patients avoid high AP routes [116].

However, evidence is limited for AQI alerts facilitating exposure-minimising behaviour. Daily text messaging regarding air quality, AP risk communication and self-care increased behaviours to reduce exposure to outdoor air pollutants versus standard of care in pregnant women [106, 107]. In contrast, adherence to health advice accompanying AQI alerts in another study was suboptimal [117]. Furthermore, receiving information from an HCP significantly increased knowledge of the AQI for individuals with respiratory disease versus no information but did not affect behaviour modification in response to index values [118].

Wearable sensors/monitors integrated into different mobile or electronic devices (including Global Positioning System-enabled models) [119-121] may be a cost-effective way to determine AP levels and potential risk at the individual level [122, 123]. A software program using smartphone technology coupled with predictive environmental AP models provided personal exposures to AP and calculated health risks [124]. Affordable access to such devices (and associated data) can lend a sense of empowerment that may motivate protective behaviour [125]. Estimation of inhaled dose could be incorporated with other fitness monitors such as wrist-worn heart rate trackers [122]. Such technologies could be used to inform clinician decisions about risk modification; and provide alerts to HCPs and carers for susceptible individuals when intervention is required [120]. Commercialised real-time particle monitors may help monitor household AP [126], but sensitivity remains limited [127]. Further limitations of low-cost personal sensors include loss of accuracy due to age [128], temperature and humidity changes [129], sensor drifts requiring frequent recalibration, and cross-sensitivities with other ambient air pollutants [128].

Most importantly, studies assessing the ability of AP sensors to induce exposure-minimising behaviour are limited [120-123]. While use of portable pollution sensors generated greater awareness of urban AP than traditional information sources, AP-reducing behaviour change did not follow [130], underscoring the current gap between empowering patients and true benefit to health therein.

Minimising personal exposure to household AP

7. Use clean fuels [Evidence grade C], optimise household ventilation [Evidence grade C], and adopt efficient cookstoves where possible [Evidence grade D]

Recommendations

- In homes that use biomass fuel (wood, animal dung and crop residues) or coal for cooking and heating, substitute these with cleaner fuels such as biogas (methane), Liquid Petroleum Gas (LPG), electricity, or solar cookers when feasible.
- Ensure cooking areas, and all areas in the vicinity of burning mosquito coils, are well ventilated with cross ventilation (opening windows or doors), chimneys or exhaust fans.
- After prioritising the adoption of cleaner fuels and better ventilation, switch to more efficient cookstoves if resources remain sufficient.

Background and evidence

Cleaner cooking fuels

Over 3 billion people worldwide use traditional cookstoves that burn wood, animal dung or crop residues to cook food or heat water [131]. This produces very high levels of indoor air pollution (such as CO and PM) because of poor combustion efficiency [131]. Replacing biomass fuels with cleaner cooking fuels (LPG or electricity) reduced the risk of acute respiratory infection (ARI) in children <5 years of age [132], was associated with shorter hospital stays for ARIs [133], lowered the risk of all-cause mortality versus persistent solid fuel users [134], and combined with improved kitchen ventilation reduced decline of lung function and COPD incidence [135]. Replacing solid fuels for cooking with cleaner fuels also reduced respiratory symptoms in women [136], and the incidence of bronchitis, phlegm, and chest illness in women and children [137].

Improved ventilation

In some cultures, where weather permits, cooking is often conducted outdoors in well ventilated spaces and, when compared with indoor cooking, can reduce the prevalence of ARI in children < 5 years [138, 139]. Among those who cook indoors, improving ventilation reduced the levels of CO and PM [140, 141] and was associated with improved health outcomes, such as reduction in respiratory symptoms [142-144], reduced risk of asthma and prevalence of asthma-related symptoms among children [145, 146], reduced risk of lung cancer [147, 148], COPD incidence, and pneumonia [148], and improved respiratory health-related quality of life in women [141].

Burning mosquito coils is another major source of household air pollution in tropical countries; mosquito coils are typically used indoors with door and windows closed to prevent mosquitoes from entering the home [149]. When burning a mosquito coil indoors, opening a window can reduce $PM_{2.5}$ levels from 2200 μg m^{-3} to around 350 μg m^{-3}; opening a window and door can further reduce levels to 70 μg m^{-3} [149].

Household ventilation can be improved by ensuring cross-ventilation via windows and doors, or by using chimneys, flues, hoods, or exhaust fans [115]. While our recommendations are focused on combustion-related AP, ventilation may also serve to decrease the impact of chemicals in the home (for example, from cleaning products and off-gassing from carpets and furniture), although a recent review suggests that indoor volatile organic compounds are attenuated more by time than by ventilation [150].

Improved cookstoves

Traditional cookstoves are often made up of stone, mud or clay [151], and burn solid fuels inefficiently [131]. There have been several attempts to build more efficient cookstoves by engineering design and/or incorporating a fan to improve combustion [152, 153], and in laboratory settings can reduce emissions by up to 90% [153]. However, field studies have indicated that although improved cookstoves can reduce $PM_{2.5}$ levels significantly versus traditional cookstoves, they are not improved enough to achieve WHO recommended $PM_{2.5}$ levels [154].

Despite recommendations to use improved cookstoves by the WHO and the Global Initiative for Chronic Obstructive Lung Disease (GOLD) [155, 156], evidence for respiratory health benefits reported with use of improved cookstoves is minimal [133, 157, 158]. Accordingly, studies with improved cookstoves have not shown significant benefit in terms of improving quality of life among asthmatic children [159], improving lung function indices versus cooking over an open fire [160, 161], or reducing the risk of pneumonia in young children [153]. Adoption practices are sometimes incomplete [155, 162] due to efficacy as well as cultural reasons, suggesting a need for further education and training to sustain adherence and understand limitations [139, 142, 154]. The current level of evidence does not yet support the use of improved cookstoves, which may need to be combined with other AP reduction interventions to yield beneficial health effects [163, 164], but they may reasonably be adopted nonetheless as a common sense measure, when resources permit.

8. Use portable air cleaners as an indoor environmental intervention [Evidence grade C]

Recommendations

- Use portable HEPA-fitted air cleaners in most-frequented rooms of home, to help reduce respiratory health effects among the general population who face regular exposure to household AP and/or those with intermittent high-level particulate exposure.
- Avoid air cleaning technologies that may emit harmful by-products, including ionisers or ion generators that generate ozone.
- Place air cleaners where the most vulnerable occupants spend most of their time, without obstruction from furnishings.
- Regularly maintain air cleaners by following manufacturers' guidance.

Background and evidence

The use of portable air cleaners can lower indoor AP from cooking, cigarettes, and other sources as well as outdoor pollution that infiltrates indoors and these may provide an additional benefit by reducing volatile organic compounds associated with household chemicals [165]. Air filters such as HEPA filters capture particles on fibrous materials, while electronic air cleaners such as ionisers or electrostatic precipitators rely on electrostatic forces to remove airborne particles. Some air filters include adsorbent media such as activated carbon to remove gaseous air pollutants or convert them to harmless by-products [166].

Efficiency of a portable air cleaner is reported as the minimum efficiency reporting value (MERV, ranging from 1–16). Effectiveness of portable air cleaners is described by the clean air delivery rate (CADR), which is expressed in cubic feet per minute (cfm). The higher the CADR, the larger the area it can serve [166].

The use of HEPA filtration (typically equivalent to MERV 16) in living rooms and/or bedrooms has been shown to reduce indoor residential $PM_{2.5}$ concentrations between 40–72% versus baseline, control or outdoor levels [167-171]. The efficiency of these filters to reduce $PM_{2.5}$ has been shown to decrease over time [172].

HEPA filtration was also found to be effective in lowering indoor PM resulting from wildfire emissions [172]. Modelling studies estimated that portable air cleaner use during wildfires in California provided mortality-related cost-effective benefits, which would be improved further by targeting the elderly [173]. Another modelling study came to similar conclusions for using activated carbon filters in homes to reduce indoor ozone of outdoor origin [174]. Public health officials in both the US [175] and Canada [176] support use of portable air cleaners to reduce exposure to wildfire smoke inside homes.

In terms of respiratory health benefits, several interventions studies have found portable air cleaners in homes to improve outcomes [177]. A small-scale intervention study suggested cardiopulmonary benefits (indicated by markers of airway inflammation, lung function, and blood pressure) of air filter use in dormitories for 48 hours among young, healthy adults in a Chinese city with severe ambient particulate AP [178]. In a study of children and adults in Shanghai, China, a single overnight HEPA-based filtration, along with activated carbon, reduced indoor $PM_{2.5}$ concentrations and led to improved airway mechanics (airway impedance, airway resistance and small airway resistance) [167]. In a randomised intervention study, HEPA cleaners in the home reduced $PM_{2.5}$ and improved asthma symptoms in children [179]. Among children for whom the air cleaner reduced indoor PM concentrations, there was a large increase in symptom-free days [180] and improvement in asthma symptoms [181]. HEPA filters were also found to improve symptoms in patients with allergic rhinitis [182].

Few studies have investigated the benefit of adding activated carbon within a HEPA-based cleaner, to reduce gaseous pollutant concentrations, but efficacy appears poor, with one study having demonstrated NO_2 concentration reductions of approximately 20% versus baseline, with diminishing benefit over time [183]. Studies assessing whether gas phase filtration or ionisers in air cleaners have a positive effect on human health are also scarce. A small study investigated the use of HEPA filter air cleaners with activated carbon in the living room and bedroom for 12 weeks and, while $PM_{2.5}$ levels were reduced by 43% and there was a significant improvement in peak exploratory flow (suggestive of improved asthma control) attributable to the cleaner, there was no evidence that the activated carbon was itself effective [170].

Effect modifiers – interventions to modify individual risk factors

9. Treat and manage of respiratory conditions [Evidence grade D]

Recommendations

- Maximise control of airway disease through optimised care (e.g., symptom and airflow monitoring, medications, vaccinations).

- Promote primary, secondary, and tertiary interventions (e.g., reducing obesity, promoting physical activity, smoking cessation, and avoidance of second-hand smoke) that may attenuate the burden of cardiopulmonary disease associated with AP exposure.

Background and evidence

Chronic respiratory conditions such as asthma and COPD may make individuals more susceptible to the adverse health effects associated with exposure to AP. Consensus recommendations for managing COPD include limiting exposure to ambient and household AP, as indicated in the GINA strategy for asthma management and prevention [12, 156].

Optimising an individual's level of asthma control may influence respiratory response to in-vehicle exposures during rush-hour commuting with one study in the US showing that the largest postcommute increases in exhaled nitric oxide occurred in participants with below-median asthma control, and higher $PM_{2.5}$ was associated with a lower forced expiratory volume in the first second (FEV_1) % predicted in this group [184]. Amongst Japanese children with asthma, exacerbation of respiratory signs and symptoms (% max peak expiratory flow and coughing) associated with oxidant exposure from ambient AP, appeared greater in those who were not using long-term medications than those who were [185].

There is limited evidence for benefit of inhaled steroids for those with asthma faced with air pollution [186]. In a study of children with asthma, those not using corticosteroid medications experienced the greatest increase in fractional exhaled nitric oxide per inter-quartile range increase of $PM_{2.5}$ oxidative burden [187]. However, there is not a clear dose-response (higher dose of inhaled steroids does not appear associated with greater benefit) and caution about the long-term effectiveness of inhaled steroids to mitigate effects of AP have been raised [186].

Furthermore, an analysis of effect modification by daily use of asthma controller medications on airway responsiveness in a large randomised longitudinal asthma study of more than 1,000 individuals found that treatment (with budesonide and nedocromil versus placebo) augmented the negative short-term effect of CO while having no effect on the other gaseous pollutants such as O_3 and NO_2 on airway responsiveness [188].

Statins and aspirin, while useful in primary prevention of CAD, require validation of their role in AP [16]. Statins reduced ambient PM-induced lung inflammation by promoting the clearance of PM <10 µm from lung tissues [189] but evidence in humans is limited. Therefore, while a general recommendation to optimise disease control through guideline-driven care is warranted, for each particular intervention in the face of AP, there needs be scrutiny of the evidence and further research to build that evidence base.

10. Modify diet and supplement with antioxidants or anti-inflammatory agents [Evidence grade D]

Recommendation

- Although a balanced diet is important for general well-being, we do not recommend taking any dietary supplement specifically to counteract the detrimental effects of AP on respiratory health, as none has been shown convincingly to have such benefits.

Background and evidence

Inhalation of air pollutants triggers direct and indirect induction of oxidative stress and inflammation [190], two key processes driving the pathogenesis of chronic respiratory diseases such as COPD and asthma that are exacerbated by AP [191].

A diet rich in antioxidants, fibre, protein and polyunsaturated fatty acids (PUFAs), such as the Mediterranean diet [192, 193] may reduce aberrant DNA methylation associated with cancer and cardiovascular disease following PM exposure [194] and fish oil supplementation may protect against pro-allergic sensitisation effects of TRAP exposure [195]. Conversely, high fat, low-PUFA ‘Western’ diets may confer reduced protection against inflammatory insults such as AP [191-193].

Found in broccoli sprouts, sulforaphane is a potent ligand for the Nrf2 transcription factor, which regulates expression of antioxidant response element-related genes [191]. Consumption of a broccoli sprout beverage increased the excretion of carcinogenic air pollutants, including benzene, over a 12-week period suggesting detoxication of some airborne pollutants [196]. Broccoli extracts also attenuated nasal allergic response to diesel exhaust particle (DEP) in atopic individuals with baseline airway DEP hypersensitivity [197]. Further large clinical trials are necessary to confirm the potential benefits of sulforaphane.

In healthy participants, pre-treatment with N-acetylcysteine diminished DEP-induced airway responsiveness in participants with baseline airway hyperresponsiveness [198]. In a second study of similar design, pre-treatment with vitamin C and N-acetylcysteine augmented DEP-induced vasoconstriction [199]. Both studies observed a role for genetic variability in dictating responses to DEP exposure and antioxidant supplementation [198, 199].

Dietary supplementation with vitamins C and E reduced lung function decrements and bronchoconstriction induced by short-term exposure to O_3, SO_2, and PM [200] and reduced airway inflammation and improved lung function in ozone-exposed patients with asthma

[191, 193, 200]; however, other randomised controlled trials failed to show positive effects [191, 193, 200]. In pregnant women exposed to $PM_{2.5}$, insufficient vitamin C intake was associated with increased micronuclei frequency, a biomarker of genetic effects, associated with increased risk of cancer [201]. Overall, antioxidant treatments have not been properly subjected to a large Phase 3 trial, or any Phase 4 trial, in this context. It is unclear whether this is due to lack of financial incentive, or indecision as to the ideal phenotype for such study, but larger well-resourced trials seem sensible given the scope of the problem and the desire for solutions in parallel with the community's driving focus on primary exposure reduction.

Summary and conclusions

Given the well-documented negative impacts of AP on respiratory health, strategies are needed to help providers, patients, and the public minimise daily exposure [52]. Strategies will need to be tailored to the individual dependent on their levels of AP exposure, their susceptibilities to AP exposure, their health literacy, financial resources, and support networks. Advisors need to develop an approach that allows flexibility based on the perception of a given individual, given the known variability in how each person perceives and responds to the threat of AP [202]. Regardless, these strategies can be impactful, because there is no 'safe' lower limit of AP and because of the steep exposure-response curve at lower levels of AP [2]. The benefits may be even more pronounced for susceptible individuals such as those with chronic pulmonary conditions, at extremes of age [51, 74, 106], pregnant women, and *in utero* [203].

The recommendations are summarised in Table 1 and Figure 3, and the key supporting evidence for each recommendation (from studies that included at least one respiratory health outcome) are described in Supplementary Table 3 in the online supplement.

Table 1. Recommended interventions, key supporting evidence, and the overall strength of evidence based on the evidence grading used in the GINA guidelines 2019 [12].

Recommendation	Key evidence summary from the last 6 years	Overall strength of evidence
Strategies to minimise personal exposure to ambient air pollution		
1. **Use close-fitting particulate respirators** such as N95 facemasks when ambient AP levels are high or when travelling to areas with high ambient levels of AP	Four small scale studies in healthy adults, mostly randomised and non-controlled in design suggest use of close-fitting N95 particulate respirators may reduce the impact of ambient AP on respiratory and cardiovascular health outcomes.	C
2. Shift from motorised to active travel such as cycling or walking	Several systematic reviews, health impact assessments and epidemiological studies suggest that the benefits of physical activity when actively commuting versus using motorised transport outweighed the risks associated with an increased inhaled dose of AP. In highly polluted cities ($PM_{2.5}$ of 160 µg m^{-3}) up to 30 minutes of cycling and 6 hours 15 minutes of walking per day would lead to a net reduction in all-cause mortality versus staying at home. Also, shift to active travel could improve air quality by reducing emissions.	C
3. Choose travel routes that minimise near-road AP exposure such as low traffic routes and routes with open spaces, minimise travel during peak times and avoid delays in areas of high AP where possible	While there is evidence that using low traffic versus high traffic routes can minimise AP exposure when cycling or walking, few studies have demonstrated respiratory health benefits, particularly for susceptible individuals. Only one randomised, controlled study found that older subjects and adults with COPD should select walking routes with low levels of traffic versus high levels to avoid negating the cardiorespiratory benefits of exercise.	C
4. Optimise driving style and vehicle settings for example drive with windows	To minimise individual exposure to TRAP, evidence from comparative studies support driving with windows closed when in traffic, maintaining car air filtration systems, keeping	D

closed when in traffic, maintain car air filtration systems and avoiding engine idling	the air on internal circulation and avoiding engine idling. However, no studies were identified that examined the effect of driving style, vehicle or engine settings on pulmonary function. Despite a lack of clinical studies on health outcomes, the potential benefit of reducing AP levels means that this is an action to consider.	
5. Exercise regularly but moderate outdoor activity when and where AP levels are high	Current evidence from epidemiological and comparative studies suggests that engaging in physical activity in an air-polluted environment may not completely negate the positive effects of exercise. Individuals should be advised to exercise away from traffic whenever possible and plan outdoor activities around local forecasts.	C
6. Be aware of local AP levels	Individuals should be encouraged to check their local air quality forecast and maps and use this information to make informed decisions to reduce their exposure such as seeking alternative low AP routes or moderating outdoor activities. No studies were identified that examined an association between AQI awareness and respiratory health outcomes; however, the potential benefit of knowing when AP levels are high and implementing strategies to minimise exposure means that this is an action to consider.	D
Strategies to minimise personal exposure to household air pollution		
7. **Use clean fuels, ensure adequate household ventilation** where possible, and adopt improved cookstoves where resources remain sufficient	Some small-scale, non-crossover intervention studies suggest that transitioning away from cooking with solid fuels to electric or clean-burning gas (LPG) stoves can improve respiratory health outcomes in adults and children. The GOLD guidelines recommend use of non-polluting cooking stoves and efficient ventilation to minimise exposure to indoor AP as a risk factor for developing COPD.[150]	C/D
8. Use portable air cleaners combined with measures to reduce the source of household AP and strategies to improve ventilation	There is evidence from mostly randomised, crossover intervention studies to support the use of portable air cleaners to reduce respiratory health effects among the general population who face regular exposure to household AP although evidence for benefit in older individuals is lacking. Portable air cleaners fitted with HEPA filters are most effective for filtering particles in the home.	C
Effect modifiers		

9. **Treat and manage respiratory conditions**	Effective management of COPD and asthma in patients is vital for mitigating the increased risk from ambient or indoor AP exposure. The implementation of established primary, secondary, and tertiary interventions for cardiopulmonary diseases (e.g., controlling hypertension, lowering lipids, reducing obesity, promoting physical activity, smoking cessation and avoidance of SHS) will serve to reduce the overall burden of disease associated with AP exposure.	D
10. **Modify diet and supplement** with antioxidants or anti-inflammatory agents	A healthy, balanced diet is favoured as a key determinant to health throughout life and associated with reductions in the risk of chronic lung diseases known to be compounded by AP.	D

AP: air pollution; AQI: air quality index; COPD: chronic obstructive pulmonary disease; GINA: Global Initiative for Asthma; GOLD: Global Initiative for Chronic Obstructive Lung Disease; HEPA: high efficiency particulate air; LPG: liquid petroleum gas; PM: particulate matter; SHS: second-hand smoke; TRAP: traffic-related air pollution.

These evidence-based, practical recommendations should serve as a useful reference for advising patients and the public on individual-level interventions to reduce exposure to AP and mitigate the associated respiratory health risks. While we, like others [204], reveal that the quality of the evidence is lacking overall, we have supplemented what the sub-optimal evidence suggests with expert perspective, so as to provide guidance to those who want it; it is important to give such advice to the global population that eagerly seeks a rational approach to personal decisions now. In parallel, gaps in the evidence and areas for further research are described in Table 2, motivating efforts to provide a more robust evidence base for validated advice to all of us who face the daily threat of AP.

Table 2. Gaps in the evidence and areas for further research

1. **Use facemasks under appropriate circumstances**
• Knowledge about the role of facemasks in reducing exposures to AP is rudimentary. There is a need for more extensive, rigorous and standardised testing of commercially

	available AP masks. • Studies assessing the impact of facemasks on health outcomes should include measurement of exposure reduction (by monitoring particulate concentrations inside the facepiece) to more accurately assess exposure–response relationships [19]. It would be of value to determine whether the proportion of particles removed by the mask is sufficient to provide health benefits, and how long people must wear a mask for those benefits to manifest. • Studies are needed to assess whether wearing masks that filter gaseous pollutants (in addition to fine particles) provide added respiratory benefits.
2.	**Shift from motorised to active transport whenever possible**
	• There are very limited data on long-term respiratory health effects of increased AP exposure among passive and active commuters, warranting additional research in this area. • Data on commuters' perceptions about AP exposure and how these perceptions may influence their commute in terms of route, time of day and mode of transportation are scarce. Understanding these perceptions may help guide future educational efforts aimed at reducing active commuters' air pollution exposures [37].
3.	**Choose travel routes that minimise near-road AP exposure**
	• Children and their families should be provided with information on how to minimise exposure to TRAP by prioritising low AP routes, integrated with cycling and walking plans when commuting to school [74]. • Mobile phone applications, news feeds and websites can help individuals plan their activities or travel routes to minimise AP exposures [99, 205-207]. Evidence is needed to demonstrate that these interventions reduce AP exposure and lead to associated health benefits. • Much of the research focus has been on developed countries, strategies to minimise TRAP in countries such as China and India where there has been a sharp increase in the number of motor vehicles needs further exploration; in these countries the options to avoid highly polluted routes are often limited or non-existent.
4.	**Optimise driving style and vehicle settings**
	• There is evidence to show that changes to driving style and vehicle settings can lower levels of local AP; however, studies are needed to determine the potential health benefits associated with reduced exposure to traffic-related AP related to changes in

driving behaviours.

- There is a need to identify approaches that encourage more efficient, less polluting driving behaviour.
- While electric cars are the vehicles of the future for their low emissions, they still generate pollutants, for example, from tires and other parts of engine, and the impact on respiratory health needs to be studied.

5. Moderate outdoor physical activity when and where AP levels are high

- The level of AP or physical activity at which exercise becomes more harmful than beneficial is not fully understood, limiting the ability to effectively balance the benefits and risks.
- Studies are needed to assess whether associations between long- and short-term concentrations of AP and indicators of health risks can be modified by levels and types of physical activity, as well as the locations where physical activity is performed.
- Gene–environment interaction is an emerging focus of research and the role of genetics in the health effects of combined physical activity and AP exposure warrants further investigation.

6. Monitor AP levels

- Current data on efficacy of AQI alerts and wearable technology in increasing AP-protective behaviour is conflicting and often relies on self-report [112]. Further research is needed to establish how individuals can be best motivated and assisted to act on advice to reduce AP exposure.
- Standardisation of personal exposure monitors is needed to ensure accurate detection of major air pollutants, and their precision, accuracy and generalisability in capturing long-term or usual exposures requires further evaluation.
- Wearable sensors and location-based monitoring fail to account for the impact of ventilation rate on inhalation of pollutants – newer personal monitoring devices that incorporate these measurements are necessary to provide more accurate measures of AP exposure.
- The full benefits of knowing one's personal AP exposure still needs to be explored and one possibility is that it may be a powerful determinant of changing behaviour towards reduced exposure.

7. Use clean fuels, ensure adequate household ventilation where possible and adopt improved cookstoves where resources remain sufficient

• Education on the respiratory health risks associated with burning solid fuels for cooking and heating is lacking. • Large-scale RCTs are needed to examine the effect of improved household ventilation on respiratory health outcomes. • Large-scale RCTs are needed to examine the effect of transitioning away from cooking with solid fuels on respiratory health outcomes. Until the findings are known, it is difficult to recommend household energy interventions that will reliably improve respiratory health.
8. Use portable air cleaners as an indoor environmental intervention
• The body of evidence supporting the role of portable air cleaners in reducing exposures to indoor air pollutants and providing benefit is growing; however, there is need for more extensive, rigorous and standardised testing of commercially available portable air cleaners, their potential to reduce exposure to household AP and provide respiratory health benefits. • More studies are needed to assess whether portable air cleaners that filter gaseous pollutants (in addition to PM) provide added respiratory benefits. • Education on the harmful effects of household AP including SHS derived from indoor cigarette smoking, in particular the association with asthma and the development of chronic lung disease in later life, is needed to foster behavioural change and improve respiratory health.
9. Treat and manage respiratory conditions
• Preliminary evidence in animal studies that pharmacological interventions such as statins, may help protect lung inflammation triggered by AP exposures need to be confirmed [189]. • Studies are needed to identify genetic polymorphisms that modify airway responses to AP, clarify the role of epigenetic changes and investigate the effectiveness of new preventive or therapeutic approaches, including for people with low levels of antioxidants.
10. Modify diet and supplement with antioxidants or anti-inflammatory agents
• Large, well-designed RCTs are necessary to confirm the beneficial effects of high fruit and vegetable intake, and of the Mediterranean diet, on respiratory health outcomes and effects of AP exposure. • Clearer mechanistic understanding and assessment of combinations of supplements and

AP exposures are warranted to establish whether there are optimal supplement regimens for particular populations, diseases, genotypes or patterns of pollutant exposure.

- Sulphoraphane supplementation may present a promising mechanism to reduce the impact of AP [196, 197] and further large RCTs are needed.

AP: air pollution; AQI: air quality index; PM: particulate matter; RCT: randomised controlled trial; SHS: second-hand smoke; TRAP: traffic-related air pollution.

Acknowledgements

Editorial writing assistance, supported financially by GSK, was provided by Gill McFeat of Ogilvy 4D. GSK had no role in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the paper for publication.

Declaration of interests

CC, SS, GW, and KFC have received honoraria for participating in Advisory Board meetings of GSK and are Scientific Advisors to The Clean Breathing Institute of GSK Consumer Healthcare. KFC has also received honoraria for participating in Advisory Board meetings of AZ, Novartis, Merck, BI, and TEVA regarding treatments for asthma and COPD and has also been remunerated for speaking engagements.

References

1. World Health Organization. Ten threats to global health in 2019. https://www.who.int/emergencies/ten-threats-to-global-health-in-2019. Date last accessed: Feb 08, 2019.

2. Burnett R, Chen H, Szyszkowicz M, Fann N, Hubbell B, Pope CA, Apte JS, Brauer M, Cohen A, Weichenthal S, Coggins J, Di Q, Brunekreef B, Frostad J, Lim SS, Kan H, Walker KD, Thurston GD, Hayes RB, Lim CC, Turner MC, Jerrett M, Krewski D, Gapstur SM, Diver WR, Ostro B, Goldberg D, Crouse DL, Martin RV, Peters P, Pinault L, Tjepkema M, van Donkelaar A, Villeneuve PJ, Miller AB, Yin P, Zhou M, Wang L, Janssen NAH, Marra M, Atkinson RW, Tsang H, Quoc Thach T, Cannon JB, Allen RT, Hart JE, Laden F, Cesaroni G, Forastiere F, Weinmayr G, Jaensch A, Nagel G, Concin H, Spadaro JV. Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. *Proc Natl Acad Sci U S A* 2018; 115: 9592–9597.

3. Landrigan PJ, Fuller R, Acosta NJR, Adeyi O, Arnold R, Basu N, Baldé AB, Bertollini R, Bose-O'Reilly S, Boufford JI, Breysse PN, Chiles T, Mahidol C, Coll-Seck AM, Cropper ML, Fobil J, Fuster V, Greenstone M, Haines A, Hanrahan D, Hunter D, Khare M, Krupnick A, Lanphear B, Lohani B, Martin K, Mathiasen KV, McTeer MA, Murray CJL, Ndahimananjara JD, Perera F, Potočnik J, Preker AS, Ramesh J, Rockström J, Salinas C, Samson LD, Sandilya K, Sly PD, Smith KR, Steiner A, Stewart RB, Suk WA, van Schayck OCP, Yadama GN, Yumkella K, Zhong M. The Lancet Commission on pollution and health. *Lancet* 2018; 391: 462–512.

4. Assad NA, Kapoor V, Sood A. Biomass smoke exposure and chronic lung disease. *Curr Opin Pulm Med* 2016; 22: 150–157.

5. Traboulsi H, Guerrina N, Iu M, Maysinger D, Ariya P, Baglole C. Inhaled pollutants: the molecular scene behind respiratory and systemic diseases associated with ultrafine particulate matter. *Int J Mol Sci* 2017; 18: 243.

6. Hedley AJ, Wong CM, Thach TQ, Ma S, Lam TH, Anderson HR. Cardiorespiratory and all-cause mortality after restrictions on sulphur content of fuel in Hong Kong: an intervention study. *Lancet* 2002; 360: 1646–1652.

7. Clancy L, Goodman P, Sinclair H, Dockery DW. Effect of air-pollution control on death rates in Dublin, Ireland: an intervention study. *Lancet* 2002; 360: 1210–1214.

8. Shi J, Lin Z, Chen R, Wang C, Yang C, Cai J, Lin J, Xu X, Ross JA, Zhao Z, Kan H. Cardiovascular benefits of wearing particulate-filtering respirators: a randomized crossover trial. *Environ Health Perspect* 2017; 125: 175–180.

9. Pope CA, Cropper M, Coggins J, Cohen A. Health benefits of air pollution abatement policy: role of the shape of the concentration–response function. *J Air Waste Manag Assoc* 2015; 65: 516–522.

10. Powell P, Brunekreef B, Grigg J. How do you explain the risk of air pollution to your patients? *Breathe* 2016; 12: 201–203.

11. Royal College of Physicians. Every breath we take: the lifelong impact of air pollution. London: RCP; 2016.

12. Global Initiative for Asthma. Global Strategy for Asthma Management and Prevention, 2019. https://ginasthma.org/wp-content/uploads/2019/06/GINA-2019-main-report-June-2019-wms.pdf. Date last accessed: Oct 09, 2019.

13. Centers for Disease Control and Prevention. Non-occupational uses of respiratory protection – what public health organizations and users need to know. January 2018. https://blogs.cdc.gov/niosh-science-blog/2018/01/04/respirators-public-use. Date last accessed: Feb 06, 2019.

14. US Food and Drug Administration. Masks and N95 respirators. May 2018. https://www.fda.gov/medicaldevices/productsandmedicalprocedures/generalhospitaldevicesandsupplies/personalprotectiveequipment/ucm055977.htm. Date last accessed: Feb 06, 2019.

15. Rajper SA, Ullah S, Li Z. Exposure to air pollution and self-reported effects on Chinese students: A case study of 13 megacities. *PLoS One* 2018; 13: e0194364.

16. Laumbach R, Meng Q, Kipen H. What can individuals do to reduce personal health risks from air pollution? *J Thorac Dis* 2015; **7**: 96–107.

17. Jiang XQ, Mei XD, Feng D. Air pollution and chronic airway diseases: what should people know and do? *J Thorac Dis* 2016; 8: E31–40.

18. Pacitto A, Amato F, Salmatonidis A, Moreno T, Alastuey A, Reche C, Buonanno G, Benito C, Querol X. Effectiveness of commercial face masks to reduce personal PM exposure. *Sci Total Environ* 2019; 650: 1582–1590.

19. Cherrie JW, Apsley A, Cowie H, Steinle S, Mueller W, Lin C, Horwell CJ, Sleeuwenhoek A, Loh M. Effectiveness of face masks used to protect Beijing residents against particulate air pollution. *Occup Environ Med* 2018; 75: 446–452.

20. Yu Y, Jiang L, Zhuang Z, Liu Y, Wang X, Liu J, Yang M, Chen W. Fitting characteristics of N95 filtering-facepiece respirators used widely in China. *PLoS ONE* 2014; 9: e85299.

21. Johnson AT. Respirator masks protect health but impact performance: a review. *J Biol Eng* 2016; 10: 4.

22. MacIntyre CR, Seale H, Dung TC, Hien NT, Nga PT, Chughtai AA, Rahman B, Dwyer DE, Wang Q. A cluster randomised trial of cloth masks compared with medical masks in healthcare workers. *BMJ Open* 2015; 5: e006577–e006577.

23. Guan W-J, Zheng X-Y, Chung KF, Zhong N-S. Impact of air pollution on the burden of chronic respiratory diseases in China: time for urgent action. *Lancet* 2016; 388: 1939–1951.

24. Guan T, Hu S, Han Y, Wang R, Zhu Q, Hu Y, Fan H, Zhu T. The effects of facemasks on airway inflammation and endothelial dysfunction in healthy young adults: a double-blind, randomized, controlled crossover study. *Part Fibre Toxicol* 2018; 15: 30.

25. Shakya KM, Noyes A, Kallin R, Peltier RE. Evaluating the efficacy of cloth facemasks in reducing particulate matter exposure. *J Expo Sci Environ Epidemiol* 2017; 27: 352–357.

26. Patel D, Shibata T, Wilson J, Maidin A. Challenges in evaluating PM concentration levels, commuting exposure, and mask efficacy in reducing PM exposure in growing, urban communities in a developing country. *Sci Total Environ* 2016; 543: 416–424.

27. Shakya KM, Rupakheti M, Aryal K, Peltier RE. Respiratory effects of high levels of particulate exposure in a cohort of traffic police in Kathmandu, Nepal. *J Occup Environ Med* 2016; 58: e218–e225.

28. Yang X, Jia X, Dong W, Wu S, Miller MR, Hu D, Li H, Pan L, Deng F, Guo X. Cardiovascular benefits of reducing personal exposure to traffic-related noise and particulate air pollution: a randomized crossover study in the Beijing subway system. *Indoor Air* 2018; 28: 777–786.

29. Laumbach RJ, Kipen HM, Ko S, Kelly-McNeil K, Cepeda C, Pettit A, Ohman-Strickland P, Zhang L, Zhang J, Gong J, Veleeparambil M, Gow AJ. A controlled trial of acute effects of human exposure to traffic particles on pulmonary oxidative stress and heart rate variability. *Part Fibre Toxicol* 2014; 11: 45.

30. Wang A, Fan R, Zhou X, Hao S, Zheng X, Yang Y. Hot-pressing method to prepare imidazole-based Zn(II) metal–organic complexes coatings for highly efficient air filtration. *ACS Appl Mater Interfaces* 2018; 10: 9744–9755.

31. Wang N, Cai M, Yang X, Yang Y. Electret nanofibrous membrane with enhanced filtration performance and wearing comfortability for face mask. *J Colloid Interface Sci* 2018; 530: 695–703.

32. Zhao Y, Low Z-X, Feng S, Zhong Z, Wang Y, Yao Z. Multifunctional hybrid porous filters with hierarchical structures for simultaneous removal of indoor VOCs, dusts and microorganisms. *Nanoscale* 2017; 9: 5433–5444.

33. Open Biomedical Initiative. Breathe easier with Sendinaden's 3D printed Pattern Breathe mask. http://www.openbiomedical.org/breathe-easier-with-sendinadens-3d-printed-pattern-breathe-mask/. Date last accessed: Feb 06, 2019.

34. Dons E, Int Panis L, Van Poppel M, Theunis J, Wets G. Personal exposure to black carbon in transport microenvironments. *Atmos Environ* 2012; 55: 392–398.

35. de Nazelle A, Bode O, Orjuela JP. Comparison of air pollution exposures in active vs. passive travel modes in European cities: A quantitative review. *Environ Int* 2017; 99: 151–160.

36. Karanasiou A, Viana M, Querol X, Moreno T, de Leeuw F. Assessment of personal exposure to particulate air pollution during commuting in European cities - recommendations and policy implications. *Sci Total Environ* 2014; 490: 785–797.

37. Chaney RA, Sloan CD, Cooper VC, Robinson DR, Hendrickson NR, McCord TA, Johnston JD. Personal exposure to fine particulate air pollution while commuting: an examination of six transport modes on an urban arterial roadway. *PLoS One* 2017; 12: e0188053.

38. Okokon EO, Yli-Tuomi T, Turunen AW, Taimisto P, Pennanen A, Vouitsis I, Samaras Z, Voogt M, Keuken M, Lanki T. Particulates and noise exposure during bicycle, bus and car commuting: A study in three European cities. *Environ Res* 2017; 154: 181–189.

39. Ozgen S, Ripamonti G, Malandrini A, S. Ragettli M, Lonati G. Particle number and mass exposure concentrations by commuter transport modes in Milan, Italy. *AIMS Environ Sci* 2016; 3: 168–184.

40. Carvalho AM, Krecl P, Targino AC. Variations in individuals' exposure to black carbon particles during their daily activities: a screening study in Brazil. *Environ Sci Pollut Res Int* 2018; 25: 18412–18423.

41. Hankey S, Lindsey G, Marshall JD. Population-level exposure to particulate air pollution during active travel: planning for low-exposure, health-promoting cities. *Environ Health Perspect* 2017; 125: 527–534.

42. Good N, Mölter A, Ackerson C, Bachand A, Carpenter T, Clark ML, Fedak KM, Kayne A, Koehler K, Moore B, L'Orange C, Quinn C, Ugave V, Stuart AL, Peel JL, Volckens J. The Fort Collins Commuter Study: impact of route type and transport mode on personal exposure to multiple air pollutants. *J Expo Sci Environ Epidemiol* 2016; 26: 397–404.

43. Cepeda M, Schoufour J, Freak-Poli R, Koolhaas CM, Dhana K, Bramer WM, Franco OH. Levels of ambient air pollution according to mode of transport: a systematic review. *Lancet Public Health* 2017; 2: e23–e34.

44. Kumar P, Rivas I, Singh AP, Ganesh VJ, Ananya M, Frey HC. Dynamics of coarse and fine particle exposure in transport microenvironments. *npj Climate and Atmospheric Science* 2018; 1: 11.

45. Woodcock J, Tainio M, Cheshire J, O'Brien O, Goodman A. Health effects of the London bicycle sharing system: health impact modelling study. *BMJ* 2014; 348: g425.

46. Doorley R, Pakrashi V, Ghosh B. Quantifying the health impacts of active travel: assessment of methodologies. *Transp Rev* 2015; 35: 559–582.

47. Mueller N, Rojas-Rueda D, Cole-Hunter T, de Nazelle A, Dons E, Gerike R, Götschi T, Int Panis L, Kahlmeier S, Nieuwenhuijsen M. Health impact assessment of active transportation: A systematic review. *Prev Med* 2015; 76: 103–114.

48. Xia T, Nitschke M, Zhang Y, Shah P, Crabb S, Hansen A. Traffic-related air pollution and health co-benefits of alternative transport in Adelaide, South Australia. *Environ Int* 2015; 74: 281–290.

49. Andersen ZJ, de Nazelle A, Mendez MA, Garcia-Aymerich J, Hertel O, Tjønneland A, Overvad K, Raaschou-Nielsen O, Nieuwenhuijsen MJ. A study of the combined effects of physical activity and air pollution on mortality in elderly urban residents: the Danish diet, cancer, and health cohort. *Environ Health Perspect* 2015; 123: 557–563.

50. Tainio M, de Nazelle AJ, Götschi T, Kahlmeier S, Rojas-Rueda D, Nieuwenhuijsen MJ, de Sá TH, Kelly P, Woodcock J. Can air pollution negate the health benefits of cycling and walking? *Prev Med* 2016; 87: 233–236.

51. Sinharay R, Gong J, Barratt B, Ohman-Strickland P, Ernst S, Kelly FJ, Zhang J, Collins P, Cullinan P, Chung KF. Respiratory and cardiovascular responses to walking down a traffic-polluted road compared with walking in a traffic-free area in participants aged 60 years and older with chronic lung or heart disease and age-matched healthy controls: a randomised, crossover study. *Lancet* 2018; 391: 339–349.

52. National Institute for Health and Care Excellence. Air pollution: outdoor air quality and health. https://www.nice.org.uk/guidance/qs181/documents/briefing-paper. Date last accessed: Feb 04, 2019.

53. Environmental Protection Agency. AirNow. You can help keep the air cleaner - every day! https://airnow.gov/index.cfm?action=resources.whatyoucando#trans. Date last accessed: Feb 05, 2019.

54. Raza W, Forsberg B, Johansson C, Sommar JN. Air pollution as a risk factor in health impact assessments of a travel mode shift towards cycling. *Glob Health Action* 2018; 11: 1429081.

55. Gaffney AW, Hang J-Q, Lee M-S, Su L, Zhang F-Y, Christiani DC. Commuting mode and pulmonary function in Shanghai, China. *Eur Respir J* 2016; 47: 733–741.

56. Jereb B, Batkovič T, Herman L, Šipek G, Kovše Š, Gregorič A, Močnik G. Exposure to black carbon during bicycle commuting–alternative route selection. *Atmosphere* 2018; 9: 21.

57. Davies G, Whyatt JD. A network-based approach for estimating pedestrian journey-time exposure to air pollution. *Sci Total Environ* 2014; 485-486: 62–70.

58. Dirks K, Wang J, Khan A, Rushton C. Air pollution exposure in relation to the commute to school: a Bradford UK case study. *Int J Environ Res Public Health* 2016; 13: 1064.

59. Goel A, Kumar P. A review of fundamental drivers governing the emissions, dispersion and exposure to vehicle-emitted nanoparticles at signalised traffic intersections. *Atmos Environ* 2014; 97: 316–331.

60. Goel A, Kumar P. Characterisation of nanoparticle emissions and exposure at traffic intersections through fast–response mobile and sequential measurements. *Atmos Environ* 2015; 107: 374–390.

61. Choi W, Ranasinghe D, Bunavage K, DeShazo JR, Wu L, Seguel R, Winer AM, Paulson SE. The effects of the built environment, traffic patterns, and micrometeorology on street level ultrafine particle concentrations at a block scale: results from multiple urban sites. *Sci Total Environ* 2016; 553: 474–485.

62. Jarjour S, Jerrett M, Westerdahl D, de Nazelle A, Hanning C, Daly L, Lipsitt J, Balmes J. Cyclist route choice, traffic-related air pollution, and lung function: a scripted exposure study. *Environ Health* 2013; 12: 14.

63. Goel A, Kumar P. Zone of influence for particle number concentrations at signalised traffic intersections. *Atmos Environ* 2015; 123: 25–38.

64. Ramos CA, Silva JR, Faria T, Wolterbeek TH, Almeida SM. Exposure assessment of a cyclist to particles and chemical elements. *Environ Sci Pollut Res Int* 2017; 24: 11879–11889.

65. Park H-Y, Gilbreath S, Barakatt E. Respiratory outcomes of ultrafine particulate matter (UFPM) as a surrogate measure of near-roadway exposures among bicyclists. *Environ Health* 2017; 16: 6.

66. Hatzopoulou M, Weichenthal S, Dugum H, Pickett G, Miranda-Moreno L, Kulka R, Andersen R, Goldberg M. The impact of traffic volume, composition and road geometry on personal air pollution exposures among cyclists in Montreal, Canada. *J Expo Sci Environ Epidemiol* 2013; 23: 46–51.

67. MacNaughton P, Melly S, Vallarino J, Adamkiewicz G, Spengler JD. Impact of bicycle route type on exposure to traffic-related air pollution. *Sci Total Environ* 2014; 490: 37–43.

68. Ham W, Vijayan A, Schulte N, Herner JD. Commuter exposure to $PM_{2.5}$, BC, and UFP in six common transport microenvironments in Sacramento, California. *Atmos Environ* 2017; 167: 335–345.

69. Pattinson W, Kingham S, Longley I, Salmond J. Potential pollution exposure reductions from small-distance bicycle lane separations. *J Transp Health* 2017; 4: 40–52

70. Hooper LG, Kaufman JD. Ambient air pollution and clinical implications for susceptible populations. *Ann Am Thorac Soc* 2018; 15: S64–S68.

71. Soyiri IN, Alcock I. Green spaces could reduce asthma admissions. *Lancet Respir Med* 2018; 6: e1.

72. Braubach M, Egorov A, Mudu P, Wolf T, Ward Thompson C, Martuzzi M. Effects of urban green space on environmental health, equity and resilience. *In:* Kabisch N, Korn H, Stadler J, Bonn A, eds. Nature-Based Solutions to Climate Change Adaptation in Urban Areas. Springer International Publishing, Cham, 2017; pp. 187–205

73. Parmes E, Pesce G, Sabel CE, Baldacci S, Bono R, Brescianini S, D'Ippolito C, Hanke W, Horvat M, Liedes H, Maio S, Marchetti P, Marcon A, Medda E, Molinier M, Panunzi S, Parkka J, Polanska K, Prud'homme J, Ricci P, Snoj Tratnik J, Squillacioti G, Stazi MA, Maesano CN, Annesi-Maesano I. Influence of residential land cover on childhood allergic and respiratory symptoms and diseases: Evidence from 9 European cohorts. *Environ Res* 2019: 108953.

74. UNICEF. The toxic school run. https://www.unicef.org.uk/wp-content/uploads/2018/09/UUK-research-briefing-The-toxic-school-run-September-2018.pdf. Date last accessed: Feb 06, 2019.

75. Kean AJ, Harley RA, Kendall GR. Effects of vehicle speed and engine load on motor vehicle emissions. *Environ Sci Technol* 2003; 37: 3739–3746.

76. Leavey A, Reed N, Patel S, Bradley K, Kulkarni P, Biswas P. Comparing on-road real-time simultaneous in-cabin and outdoor particulate and gaseous concentrations for a range of ventilation scenarios. *Atmos Environ* 2017; 166: 130–141.

77. Quiros DC, Lee ES, Wang R, Zhu Y. Ultrafine particle exposures while walking, cycling, and driving along an urban residential roadway. *Atmos Environ* 2013; 73: 185–194.

78. Williams RD, Knibbs LD. Daily personal exposure to black carbon: a pilot study. *Atmos Environ* 2016; 132: 296–299.

79. Li B, Lei X-N, Xiu G-L, Gao C-Y, Gao S, Qian N-S. Personal exposure to black carbon during commuting in peak and off-peak hours in Shanghai. *Sci Total Environ* 2015; 524−525: 237–245.

80. Kolluru SSR, Patra AK, Sahu SP. A comparison of personal exposure to air pollutants in different travel modes on national highways in India. *Sci Total Environ* 2018; 619-620: 155–164.

81. Ding H, Zhang Y, Sun H, Feng L. Analysis of the PM2.5 Distribution and the Transfer Characteristic in a Car-Cabin. *Procedia Eng* 2015; 121: 875–880.

82. Xu B, Zhu Y. Investigation on lowering commuters' in-cabin exposure to ultrafine particles. *Transp Res D Transp Environ* 2013; 18: 122–130.

83. Lee Y-Y, Lin S-L, Yuan C-S, Lin M-Y, Chen K-S. Reduction of atmospheric fine particle level by restricting the idling vehicles around a sensitive area. *J Air Waste Manag Assoc* 2018; 68: 656–670.

84. Quintana PJE, Khalighi M, Castillo Quiñones JE, Patel Z, Guerrero Garcia J, Martinez Vergara P, Bryden M, Mantz A. Traffic pollutants measured inside vehicles waiting in line at a major US-Mexico Port of Entry. *Sci Total Environ* 2018; 622-623: 236–243.

85. Kim K-H, Szulejko JE, Jo H-J, Lee M-H, Kim Y-H, Kwon E, Ma C-J, Kumar P. Measurements of major VOCs released into the closed cabin environment of different automobiles under various engine and ventilation scenarios. *Environ Pollut* 2016; 215: 340–346.

86. Ryan PH, Reponen T, Simmons M, Yermakov M, Sharkey K, Garland-Porter D, Eghbalnia C, Grinshpun SA. The impact of an anti-idling campaign on outdoor air quality at four urban schools. *Environ Sci Process Impacts* 2013; 15: 2030–2037.

87. Borken-Kleefeld J, Chen Y. New emission deterioration rates for gasoline cars – results from long-term measurements. *Atmos Environ* 2015; 101: 58–64.

88. IARC Scientific Publications. Air pollution and cancer, 2013. https://www.iarc.fr/wp-content/uploads/2018/07/AirPollutionandCancer161.pdf. Date last accessed: Feb 06, 2019.

89. Giles LV, Koehle MS. The health effects of exercising in air pollution. *Sports Med* 2014; 44: 223–249.

90. Si Q, Cardinal BJ. The health impact of air pollution and outdoor physical activity on children and adolescents in Mainland China. *J Pediatr* 2017; 180: 251–255.

91. Kubesch NJ, de Nazelle A, Westerdahl D, Martinez D, Carrasco-Turigas G, Bouso L, Guerra S, Nieuwenhuijsen MJ. Respiratory and inflammatory responses to short-term exposure to traffic-related air pollution with and without moderate physical activity. *Occup Environ Med* 2015; 72: 284–293.

92. Laeremans M, Dons E, Avila-Palencia I, Carrasco-Turigas G, Orjuela JP, Anaya E, Cole-Hunter T, de Nazelle A, Nieuwenhuijsen M, Standaert A, Van Poppel M, De Boever P, Int Panis L. Short-term effects of physical activity, air pollution and their interaction on the cardiovascular and respiratory system. *Environ Int* 2018; 117: 82–90.

93. Matt F, Cole-Hunter T, Donaire-Gonzalez D, Kubesch N, Martínez D, Carrasco-Turigas G, Nieuwenhuijsen M. Acute respiratory response to traffic-related air pollution during physical activity performance. *Environ Int* 2016; 97: 45–55.

94. Laeremans M, Dons E, Avila-Palencia I, Carrasco-Turigas G, Orjuela-Mendoza JP, Anaya-Boig E, Cole-Hunter T, A DEN, Nieuwenhuijsen M, Standaert A, M VANP, P DEB, Int Panis L. Black Carbon Reduces the Beneficial Effect of Physical Activity on Lung Function. *Med Sci Sports Exerc* 2018; 50: 1875–1881.

95. Lamichhane DK, Leem JH, Kim HC. Associations between ambient particulate matter and nitrogen dioxide and chronic obstructive pulmonary diseases in adults and effect modification by demographic and lifestyle factors. *Int J Environ Res Public Health* 2018; 15: 363.

96. Zhang Z, Hoek G, Chang L-Y, Chan T-C, Guo C, Chuang YC, Chan J, Lin C, Jiang WK, Guo Y, Vermeulen R, Yeoh E-k, Tam T, Lau AKH, Griffiths S, Lao XQ. Particulate matter air pollution, physical activity and systemic inflammation in Taiwanese adults. *Int J Hyg Environ Health* 2018; 221: 41–47.

97. Fisher JE, Loft S, Ulrik CS, Raaschou-Nielsen O, Hertel O, Tjønneland A, Overvad K, Nieuwenhuijsen MJ, Andersen ZJ. Physical activity, air pollution, and the risk of asthma and chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2016; 194: 855–865.

98. Cai DP, He YM. Daily lifestyles in the fog and haze weather. *J Thorac Dis* 2016; 8: E75–77.

99. World Air Quality Index. https://waqi.info/. Date last accessed: Feb 04, 2019.

100. Environmental Protection Agency. Air Quality Index, a guide to air quality and your health. 2014. https://www3.epa.gov/airnow/aqi_brochure_02_14.pdf. Date last accessed: Feb 05, 2019.

101. An R, Xiang X. Ambient fine particulate matter air pollution and leisure-time physical inactivity among US adults. *Public Health* 2015; 129: 1637–1644.

102. Roberts JD, Voss JD, Knight B. The association of ambient air pollution and physical inactivity in the United States. *PLoS ONE* 2014; 9: e90143.

103. An R, Zhang S, Ji M, Guan C. Impact of ambient air pollution on physical activity among adults: a systematic review and meta-analysis. *Perspect Public Health* 2018; 138: 111–121.

104. Hu L, Zhu L, Xu Y, Lyu J, Imm K, Yang L. Relationship between air quality and outdoor exercise behavior in China: a novel mobile-based study. *Int J Behav Med* 2017; 24: 520–527.

105. Ma Y, Yuan B, Fan S, Luo Y, Wen X. Association between air quality and sedentary time in 3270 Chinese adults: application of a novel technology for posture determination. *J Clin Med* 2018; 7: 257.

106. Araban M, Tavafian SS, Zarandi SM, Hidarnia AR, Burri A, Montazeri A. A behavioral strategy to minimize air pollution exposure in pregnant women: a randomized controlled trial. *Environ Health Prev Med* 2017; 22: 1.

107. Jasemzadeh M, Khafaie MA, Jaafarzadeh N, Araban M. Effectiveness of a theory-based mobile phone text message intervention for improving protective behaviors of pregnant women against air pollution: a randomized controlled trial. *Environ Sci Pollut Res Int* 2018; 25: 6648–6655.

108. Lemes S. Air Quality Index (AQI) – comparative study and assessment of an appropriate model for B&H. In: 12th Scientific/Research Symposium with International Participation Metallic And Nonmetallic Materials; 2018; Vlašić, Bosnia and Herzegovina; 2018.

109. Hu J, Ying Q, Wang Y, Zhang H. Characterizing multi-pollutant air pollution in China: comparison of three air quality indices. *Environ Int* 2015; 84: 17–25.

110. Kumari S, Jain MK. A critical review on air quality index. *In:* Singh VP, Yadav S, Yadava RN, eds. Environ Pollut. Springer Singapore, Singapore, 2018; pp. 87–102.

111. Perlmutt L, Stieb D, Cromar K. Accuracy of quantification of risk using a single-pollutant Air Quality Index. *J Expo Sci Environ Epidemiol* 2017; 27: 24–32.

112. Ramos F, Trilles S, Muñoz A, Huerta J. Promoting pollution-free routes in smart cities using air quality sensor networks. *Sensors* 2018; 18: 2507.

113. Li X, Xiao J, Lin H, Liu T, Qian Z, Zeng W, Guo L, Ma W. The construction and validity analysis of AQHI based on mortality risk: a case study in Guangzhou, China. *Environ Pollut* 2017; 220: 487–494.

114. Environmental Protection Agency. Air Quality Index - a guide to air quality and your health. https://www.airnow.gov/index.cfm?action=aqi_brochure.index. Date last accessed: Feb 05, 2019.

115. Hadley MB, Baumgartner J, Vedanthan R. Developing a clinical approach to air pollution and cardiovascular health. *Circulation* 2018; 137: 725–742.

116. Barts Health NHS Trust. Action on air pollution: collaboration and public health at scale. http://www.nhssustainabilityday.co.uk/wp-content/uploads/2014/09/Action-on-Air-Pollution_Barts-Health-NHS-Trust-June-2016.pdf. Date last accessed: Oct 22, 2018.

117. D’Antoni D, Smith L, Auyeung V, Weinman J. Psychosocial and demographic predictors of adherence and non-adherence to health advice accompanying air quality warning systems: a systematic review. *Environ Health* 2017; 16: 100.

118. Borbet TC, Gladson LA, Cromar KR. Assessing air quality index awareness and use in Mexico City. *BMC Public Health* 2018; 18: 538.

119. Hojaiji H, Kalantarian H, Bui AAT, King CE, Sarrafzadeh M. Temperature and humidity calibration of a low-cost wireless dust sensor for real-time monitoring. *2017 IEEE Sens Appl Symp (SAS) (2017)* 2017; 2017.

120. Koehler KA, Peters TM. New methods for personal exposure monitoring for airborne particles. *Curr Environ Health Rep* 2015; 2: 399–411.

121. Steinle S, Reis S, Sabel CE. Quantifying human exposure to air pollution--Moving from static monitoring to spatio-temporally resolved personal exposure assessment. *Sci Total Environ* 2013; 443: 184–193.

122. Dons E, Laeremans M, Orjuela JP, Avila-Palencia I, Carrasco-Turigas G, Cole-Hunter T, Anaya-Boig E, Standaert A, De Boever P, Nawrot T, Götschi T, de Nazelle A, Nieuwenhuijsen M, Int Panis L. Wearable sensors for personal monitoring and estimation of inhaled traffic-related air pollution: evaluation of methods. *Environ Sci Technol* 2017; 51: 1859–1867.

123. Su JG, Jerrett M, Meng Y-Y, Pickett M, Ritz B. Integrating smart-phone based momentary location tracking with fixed site air quality monitoring for personal exposure assessment. *Sci Total Environ* 2015; 506-507: 518–526.

124. Larkin A, Williams DE, Kile ML, Baird WM. Developing a smartphone software package for predicting atmospheric pollutant concentrations at mobile locations. *Comput J* 2015; 58: 1431–1442.

125. Wong-Parodi G, Dias MB, Taylor M. Effect of Using an Indoor Air Quality Sensor on Perceptions of and Behaviors Toward Air Pollution (Pittsburgh Empowerment Library Study): Online Survey and Interviews. *JMIR Mhealth Uhealth* 2018; 6: e48.

126. Dacunto PJ, Klepeis NE, Cheng K-C, Acevedo-Bolton V, Jiang R-T, Repace JL, Ott WR, Hildemann LM. Determining $PM_{2.5}$ calibration curves for a low-cost particle monitor: common indoor residential aerosols. *Environ Sci Process Impacts* 2015; 17: 1959–1966.

127. Nyarku M, Mazaheri M, Jayaratne R, Dunbabin M, Rahman MM, Uhde E, Morawska L. Mobile phones as monitors of personal exposure to air pollution: Is this the future? *PLoS One* 2018; 13: e0193150.

128. Zimmerman N, Presto AA, Kumar SPN, Gu J, Hauryliuk A, Robinson ES, Robinson AL, Subramanian R. Closing the gap on lower cost air quality monitoring: machine learning calibration models to improve low-cost sensor performance. *Atmospheric Meas Tech* 2017: 1–36.

129. Hojaiji H, Kalantarian H, Bui AAT, King CE, Sarrafzadeh M. Temperature and humidity calibration of a low-cost wireless dust sensor for real-time monitoring. *2017 IEEE Sensors Applications Symposium (SAS)* 2017.

130. Oltra C, Sala R, Boso À, Asensio SL. Public engagement on urban air pollution: an exploratory study of two interventions. *Environ Monit Assess* 2017; 189: 296.

131. Gordon SB, Bruce NG, Grigg J, Hibberd PL, Kurmi OP, Lam K-bH, Mortimer K, Asante KP, Balakrishnan K, Balmes J, Bar-Zeev N, Bates MN, Breysse PN, Buist S, Chen Z, Havens D, Jack D,

Jindal S, Kan H, Mehta S, Moschovis P, Naeher L, Patel A, Perez-Padilla R, Pope D, Rylance J, Semple S, Martin WJ. Respiratory risks from household air pollution in low and middle income countries. *Lancet Respir Med* 2014; 2: 823–860.

132. Lamichhane P, Sharma A, Mahal A. Impact of cleaner fuel use and improved stoves on acute respiratory infections: evidence from India. *Int Health* 2017; 9: 349–366.

133. Lewis JJ, Hollingsworth JW, Chartier RT, Cooper EM, Foster WM, Gomes GL, Kussin PS, MacInnis JJ, Padhi BK, Panigrahi P, Rodes CE, Ryde IT, Singha AK, Stapleton HM, Thornburg J, Young CJ, Meyer JN, Pattanayak SK. Biogas stoves reduce firewood use, household air pollution, and hospital visits in Odisha, India. *Environ Sci Technol* 2017; 51: 560–569.

134. Yu K, Qiu G, Chan K-H, Lam K-BH, Kurmi OP, Bennett DA, Yu C, Pan A, Lv J, Guo Y, Bian Z, Yang L, Chen Y, Hu FB, Chen Z, Li L, Wu T. Association of solid fuel use with risk of cardiovascular and all-cause mortality in rural China. *JAMA* 2018; 319: 1351.

135. Zhou Y, Zou Y, Li X, Chen S, Zhao Z, He F, Zou W, Luo Q, Li W, Pan Y, Deng X, Wang X, Qiu R, Liu S, Zheng J, Zhong N, Ran P. Lung function and incidence of chronic obstructive pulmonary disease after improved cooking fuels and kitchen ventilation: a 9-year prospective cohort study. *PLoS Med* 2014; 11: e1001621.

136. Downward GS, van der Zwaag HP, Simons L, Meliefste K, Tefera Y, Carreon JR, Vermeulen R, Smit LAM. Occupational exposure to indoor air pollution among bakery workers in Ethiopia; a comparison of electric and biomass cookstoves. *Environ Pollut* 2018; 233: 690–697.

137. Choi J-Y, Baumgartner J, Harnden S, Alexander BH, Town RJ, D'Souza G, Ramachandran G. Increased risk of respiratory illness associated with kerosene fuel use among women and children in urban Bangalore, India. *Occup Environ Med* 2015; 72: 114–122.

138. Buchner H, Rehfuess EA. Cooking and season as risk factors for acute lower respiratory infections in African children: a cross-sectional multi-country analysis. *PLoS One* 2015; 10: e0128933.

139. Langbein J. Firewood, smoke and respiratory diseases in developing countries-the neglected role of outdoor cooking. *PLoS One* 2017; 12: e0178631.

140. Grabow K, Still D, Bentson S. Test kitchen studies of indoor air pollution from biomass cookstoves. *Energy Sustain Dev* 2013; 17: 458–462.

141. Alexander D, Linnes JC, Bolton S, Larson T. Ventilated cookstoves associated with improvements in respiratory health-related quality of life in rural Bolivia. *J Public Health* 2014; 36: 460–466.

142. Accinelli RA, Llanos O, López LM, Pino MI, Bravo YA, Salinas V, Lazo M, Noda JR, Sánchez-Sierra M, Zárate L, da Silva J, Gianella F, Kheirandish-Gozal L, Gozal D. Adherence to reduced-polluting biomass fuel stoves improves respiratory and sleep symptoms in children. *BMC Pediatr* 2014; 14: 12.

143. Castañeda JL, Kheirandish-Gozal L, Gozal D, Accinelli RA, The Pampa Cangallo Instituto de Investigaciones de la Altura Research Group. Effect of reductions in biomass fuel exposure on symptoms of sleep apnea in children living in the peruvian andes: a preliminary field study: biomass and snoring in children. *Pediatr Pulmonol* 2013; 48: 996–999.

144. Das I, Pedit J, Handa S, Jagger P. Household air pollution (HAP), microenvironment and child health: Strategies for mitigating HAP exposure in urban Rwanda. *Environ Res Lett* 2018; 13.

145. Liu F, Zhao Y, Liu YQ, Liu Y, Sun J, Huang MM, Liu Y, Dong GH. Asthma and asthma related symptoms in 23,326 Chinese children in relation to indoor and outdoor environmental factors: the Seven Northeastern Cities (SNEC) Study. *Sci Total Environ* 2014; 497-498: 10–17.

146. Kile ML, Coker ES, Smit E, Sudakin D, Molitor J, Harding AK. A cross-sectional study of the association between ventilation of gas stoves and chronic respiratory illness in U.S. children enrolled in NHANESIII. *Environ Health* 2014; 13: 71.

147. Jin ZY, Wu M, Han RQ, Zhang XF, Wang XS, Liu AM, Zhou JY, Lu QY, Kim CH, Mu L, Zhang ZF, Zhao JK. Household ventilation may reduce effects of indoor air pollutants for prevention of lung cancer: a case-control study in a Chinese population. *PLoS One* 2014; 9: e102685.

148. Seow WJ, Hu W, Vermeulen R, Hosgood Iii HD, Downward GS, Chapman RS, He X, Bassig BA, Kim C, Wen C, Rothman N, Lan Q. Household air pollution and lung cancer in China: a review of studies in Xuanwei. *Chin J Cancer* 2014; 33: 471–475.

149. Salvi D, Limaye S, Muralidharan V, Londhe J, Madas S, Juvekar S, Biswal S, Salvi S. Indoor particulate matter < 2.5 μm in mean aerodynamic diameter and carbon monoxide levels during the burning of mosquito coils and their association with respiratory health. *Chest* 2016; 149: 459–466.

150. Holøs SB, Yang A, Lind M, Thunshelle K, Schild P, Mysen M. VOC emission rates in newly built and renovated buildings, and the influence of ventilation – a review and meta-analysis. *Int J Ventilation* 2019; 18: 153–166.

151. Balakrishnan K, Ghosh S, Ganguli B, Sambandam S, Bruce N, Barnes DF, Smith KR. State and national household concentrations of PM2.5 from solid cookfuel use: results from measurements and modeling in India for estimation of the global burden of disease. *Environ Health* 2013; 12: 77.

152. Pope D, Bruce N, Dherani M, Jagoe K, Rehfuess E. Real-life effectiveness of 'improved' stoves and clean fuels in reducing $PM_{2.5}$ and CO: systematic review and meta-analysis. *Environ Int* 2017; 101: 7–18.

153. Mortimer K, Ndamala CB, Naunje AW, Malava J, Katundu C, Weston W, Havens D, Pope D, Bruce NG, Nyirenda M, Wang D, Crampin A, Grigg J, Balmes J, Gordon SB. A cleaner burning biomass-fuelled cookstove intervention to prevent pneumonia in children under 5 years old in rural Malawi (the Cooking and Pneumonia Study): a cluster randomised controlled trial. *Lancet* 2017; 389: 167–175.

154. Muralidharan V, Sussan TE, Limaye S, Koehler K, Williams DL, Rule AM, Juvekar S, Breysse PN, Salvi S, Biswal S. Field testing of alternative cookstove performance in a rural setting of western India. *Int J Environ Res Public Health* 2015; 12: 1773–1787.

155. Bruce N, Pope D, Rehfuess E, Balakrishn K, Adair-Rohani H, Dora C. WHO indoor air quality guidelines on household fuel combustion: strategy implications of new evidence on interventions and exposure–risk functions. *Atmos Environ* 2015; 106: 451–457.

156. Global Initiative for Chronic Obstructive Lung Disease. Global strategy for diagnosis, management and prevention of COPD, 2019 report. https://goldcopd.org/wp-content/uploads/2018/11/GOLD-2019-v1.5-FINAL-04Nov2018_WMS.pdf. Date last accessed: Feb 06, 2019.

157. Quansah R, Semple S, Ochieng CA, Juvekar S, Armah FA, Luginaah I, Emina J. Effectiveness of interventions to reduce household air pollution and/or improve health in homes using solid fuel in low-and-middle income countries: a systematic review and meta-analysis. *Environ Int* 2017; 103: 73–90.

158. Thakur M, Nuyts PAW, Boudewijns EA, Flores Kim J, Faber T, Babu GR, van Schayck OCP, Been JV. Impact of improved cookstoves on women's and child health in low and middle income countries: a systematic review and meta-analysis. *Thorax* 2018; 73: 1026–1040.

159. Noonan CW, Semmens EO, Smith P, Harrar SW, Montrose L, Weiler E, McNamara M, Ward TJ. Randomized trial of interventions to improve childhood asthma in homes with wood-burning stoves. *Environ Health Perspect* 2017; 125: 097010.

160. Guarnieri M, Diaz E, Pope D, Eisen EA, Mann J, Smith KR, Smith-Sivertsen T, Bruce NG, Balmes JR. Lung function in rural Guatemalan women before and after a chimney stove intervention to reduce wood smoke exposure. *Chest* 2015; 148: 1184–1192.

161. Heinzerling AP, Guarnieri MJ, Mann JK, Diaz JV, Thompson LM, Diaz A, Bruce NG, Smith KR, Balmes JR. Lung function in woodsmoke-exposed Guatemalan children following a chimney stove intervention. *Thorax* 2016; 71: 421–428.

162. Pilishvili T, Loo JD, Schrag S, Stanistreet D, Christensen B, Yip F, Nyagol R, Quick R, Sage M, Bruce N. Effectiveness of six improved cookstoves in reducing household air pollution and their acceptability in rural Western Kenya. *PLoS One* 2016; 11: e0165529.

163. Gordon S, Mortimer K, Grigg J, Balmes J. In control of ambient and household air pollution - how low should we go? *Lancet Respir Med* 2017; 5: 918–920.

164. Mortimer K, Balmes JR. Cookstove trials and tribulations: what is needed to decrease the burden of household air pollution? *Ann Am Thorac Soc* 2018; 15: 539-541.

165. Kabrein H, Yusof MZM, Leman AM. Progresses of filtration for removing particles and gases pollutants of indoor; limitations and future direction; review article. *J Eng Applied Sci*; 11: 3633–3639.

166. Environmental Protection Agency. Residential air cleaners. https://www.epa.gov/sites/production/files/2018-07/documents/residential_air_cleaners_-_a_technical_summary_3rd_edition.pdf. Date last accessed: Feb 06, 2019.

167. Cui X, Li F, Xiang J, Fang L, Chung MK, Day DB, Mo J, Weschler CJ, Gong J, He L, Zhu D, Lu C, Han H, Zhang Y, Zhang J. Cardiopulmonary effects of overnight indoor air filtration in healthy non-smoking adults: a double-blind randomized crossover study. *Environ Int* 2018; 114: 27–36.

168. Kajbafzadeh M, Brauer M, Karlen B, Carlsten C, van Eeden S, Allen RW. The impacts of traffic-related and woodsmoke particulate matter on measures of cardiovascular health: a HEPA filter intervention study. *Occup Environ Med* 2015; 72: 394–400.

169. Karottki DG, Spilak M, Frederiksen M, Gunnarsen L, Brauner EV, Kolarik B, Andersen ZJ, Sigsgaard T, Barregard L, Strandberg B, Sallsten G, Møller P, Loft S. An indoor air filtration study in homes of elderly: cardiovascular and respiratory effects of exposure to particulate matter. *Environ Health* 2013; 12: 116.

170. Park H-K, Cheng K-C, Tetteh AO, Hildemann LM, Nadeau KC. Effectiveness of air purifier on health outcomes and indoor particles in homes of children with allergic diseases in Fresno, California: a pilot study. *J Asthma* 2017; 54: 341–346.

171. Shao D, Du Y, Liu S, Brunekreef B, Meliefste K, Zhao Q, Chen J, Song X, Wang M, Wang J, Xu H, Wu R, Wang T, Feng B, Lung CS-C, Wang X, He B, Huang W. Cardiorespiratory responses of air filtration: a randomized crossover intervention trial in seniors living in Beijing. *Sci Total Environ* 2017; 603-604: 541–549.

172. Barn P, Gombojav E, Ochir C, Laagan B, Beejin B, Naidan G, Boldbaatar B, Galsuren J, Byambaa T, Janes C, Janssen PA, Lanphear BP, Takaro TK, Venners SA, Webster GM, Yuchi W, Palmer CD, Parsons PJ, Roh YM, Allen RW. The effect of portable HEPA filter air cleaners on indoor PM2.5 concentrations and second hand tobacco smoke exposure among pregnant women in Ulaanbaatar, Mongolia: The UGAAR randomized controlled trial. *Sci Total Environ* 2018; 615: 1379–1389.

173. Fisk WJ, Chan WR. Health benefits and costs of filtration interventions that reduce indoor exposure to PM2.5 during wildfires. *Indoor Air* 2017; 27: 191–204.

174. Aldred JR, Darling E, Morrison G, Siegel J, Corsi RL. Benefit-cost analysis of commercially available activated carbon filters for indoor ozone removal in single-family homes. *Indoor Air* 2016; 26: 501–512.

175. Environmental Protection Agency. Wildfire smoke. A guide for public health officials. https://www3.epa.gov/airnow/wildfire_may2016.pdf. Date last accessed: Feb 06, 2019.

176. Elliott C. Guidance for BC public health decision makers during wildfire smoke events, 2014. http://www.bccdc.ca/resource-gallery/Documents/Guidelines%20and%20Forms/Guidelines%20and%20Manuals/Health-Environment/WFSG_BC_guidance_2014_09_03trs.pdf. Date last accessed: Feb 06, 2019.

177. Fisk WJ. Health benefits of particle filtration. *Indoor Air* 2013; 23: 357–368.

178. Chen R, Zhao A, Chen H, Zhao Z, Cai J, Wang C, Yang C, Li H, Xu X, Ha S, Li T, Kan H. Cardiopulmonary benefits of reducing indoor particles of outdoor origin. *J Am Coll Cardiol* 2015; 65: 2279–2287.

179. Butz AM. A randomized trial of air cleaners and a health coach to improve indoor air quality for inner-city children with asthma and secondhand smoke exposure. *Arch Pediatr Adolesc Med* 2011; 165: 741.

180. Peng RD, Butz AM, Hackstadt AJ, Williams DAL, Diette GB, Breysse PN, Matsui EC. Estimating the health benefit of reducing indoor air pollution in a randomized environmental intervention. *J R Stat Soc Ser A Stat Soc* 2015; 178: 425–443.

181. Hackstadt AJ, Matsui EC, Williams DAL, Diette GB, Breysse PN, Butz AM, Peng RD. Inference for environmental intervention studies using principal stratification. *Stat Med* 2014; 33: 4919–4933.

182. Jia-Ying L, Zhao C, Jia-Jun G, Zi-Jun G, Xiao L, Bao-Qing S. Efficacy of air purifier therapy in allergic rhiniti. *Asian Pac J Allergy Immunol* 2018; 36: 217–221.

183. Paulin LM, Diette GB, Scott M, McCormack MC, Matsui EC, Curtin-Brosnan J, Williams DL, Kidd-Taylor A, Shea M, Breysse PN, Hansel NN. Home interventions are effective at decreasing indoor nitrogen dioxide concentrations. *Indoor Air* 2014; 24: 416–424

184. Mirabelli MC, Golan R, Greenwald R, Raysoni AU, Holguin F, Kewada P, Winquist A, Flanders WD, Sarnat JA. Modification of traffic-related respiratory response by asthma control in a population of car commuters. *Epidemiology* 2015; 26: 546–555.

185. Hasunuma H, Yamazaki S, Tamura K, Hwang YH, Ono R, Amimoto Y, Askew DJ, Odajima H. Association between daily ambient air pollution and respiratory symptoms in children with asthma and healthy children in western Japan. *J Asthma* 2018; 55: 712–719.

186. Rider CF, Carlsten C. Air pollution and resistance to inhaled glucocorticoids: Evidence, mechanisms and gaps to fill. *Pharmacol Ther* 2019; 194: 1–21.

187. Maikawa CL, Weichenthal S, Wheeler AJ, Dobbin NA, Smargiassi A, Evans G, Liu L, Goldberg MS, Pollitt KJG. Particulate oxidative burden as a predictor of exhaled nitric oxide in children with asthma. *Environ Health Perspect* 2016; 124: 1616–1622.

188. Ierodiakonou D, Zanobetti A, Coull BA, Melly S, Postma DS, Boezen HM, Vonk JM, Williams PV, Shapiro GG, McKone EF, Hallstrand TS, Koenig JQ, Schildcrout JS, Lumley T, Fuhlbrigge AN, Koutrakis P, Schwartz J, Weiss ST, Gold DR. Ambient air pollution, lung function, and airway responsiveness in asthmatic children. *J Allergy Clin Immunol* 2016; 137: 390–399.

189. Miyata R, Bai N, Vincent R, Sin DD, Van Eeden SF. Statins reduce ambient particulate matter-induced lung inflammation by promoting the clearance of particulate matter < 10 μm from lung tissues. *Chest* 2013; 143: 452–460.

190. Cosselman KE, Navas-Acien A, Kaufman JD. Environmental factors in cardiovascular disease. *Nat Rev Cardiol* 2015; 12: 627–642.

191. Péter S, Holguin F, Wood L, Clougherty J, Raederstorff D, Antal M, Weber P, Eggersdorfer M. Nutritional solutions to reduce risks of negative health impacts of air pollution. *Nutrients* 2015; 7: 10398–10416

192. Guilleminault L, Williams E, Scott H, Berthon B, Jensen M, Wood L. Diet and asthma: is it time to adapt our message? *Nutrients* 2017; 9: 1227.

193. Whyand T, Hurst JR, Beckles M, Caplin ME. Pollution and respiratory disease: can diet or supplements help? A review. *Respir Res* 2018; 19: 79.

194. Barchitta M, Maugeri A, Quattrocchi A, Barone G, Mazzoleni P, Catalfo A, De Guidi G, Iemmolo MG, Crimi N, Agodi A. Mediterranean diet and particulate matter exposure are associated with LINE-1 methylation: results from a cross-sectional study in women. *Frontiers in Genetics* 2018; 9: 514.

195. Hansell AL, Bakolis I, Cowie CT, Belousova EG, Ng K, Weber-Chrysochoou C, Britton WJ, Leeder SR, Tovey ER, Webb KL, Toelle BG, Marks GB. Childhood fish oil supplementation modifies associations between traffic related air pollution and allergic sensitisation. *Environ Health* 2018; 17: 27.

196. Egner PA, Chen JG, Zarth AT, Ng DK, Wang JB, Kensler KH, Jacobson LP, Munoz A, Johnson JL, Groopman JD, Fahey JW, Talalay P, Zhu J, Chen TY, Qian GS, Carmella SG, Hecht SS, Kensler TW. Rapid and sustainable detoxication of airborne pollutants by broccoli sprout beverage: results of a randomized clinical trial in China. *Cancer Prev Res* 2014; 7: 813–823.

197. Heber D, Li Z, Garcia-Lloret M, Wong AM, Lee TY, Thames G, Krak M, Zhang Y, Nel A. Sulforaphane-rich broccoli sprout extract attenuates nasal allergic response to diesel exhaust particles. *Food Funct* 2014; 5: 35–41.

198. Carlsten C, MacNutt MJ, Zhang Z, Sava F, Pui MM. Anti-oxidant N-acetylcysteine diminishes diesel exhaust-induced increased airway responsiveness in person with airway hyper-reactivity. *Toxicol Sci* 2014; 139: 479–487.

199. Sack CS, Jansen KL, Cosselman KE, Trenga CA, Stapleton PL, Allen J, Peretz A, Olives C, Kaufman JD. Pretreatment with antioxidants augments the acute arterial vasoconstriction caused by diesel exhaust inhalation. *Am J Respir Crit Care Med* 2016; 193: 1000–1007.

200. Tong H. Dietary and pharmacological intervention to mitigate the cardiopulmonary effects of air pollution toxicity. *Biochim Biophys Acta* 2016; 1860: 2891–2898.

201. O'Callaghan-Gordo C, Fthenou E, Pedersen M, Espinosa A, Chatzi L, Beelen R, Chalkiadaki G, Decordier I, Hoek G, Merlo DF, Nieuwenhuijsen M, Roumeliotaki T, Vafeiadi M, Vande Loock K, Kleinjans J, Stephanou E, Kirsch-Volders M, Kogevinas M. Outdoor air pollution exposures and micronuclei frequencies in lymphocytes from pregnant women and newborns in Crete, Greece (Rhea cohort). *Environ Res* 2015; 143: 170–176.

202. Ban J, Zhou L, Zhang Y, Brooke Anderson G, Li T. The health policy implications of individual adaptive behavior responses to smog pollution in urban China. *Environ Int* 2017; 106: 144–152.

203. Li X, Huang S, Jiao A, Yang X, Yun J, Wang Y, Xue X, Chu Y, Liu F, Liu Y, Ren M, Chen X, Li N, Lu Y, Mao Z, Tian L, Xiang H. Association between ambient fine particulate matter and preterm birth or term low birth weight: an updated systematic review and meta-analysis. *Environ Pollut* 2017; 227: 596-605.

204. Burns J, Boogaard H, Polus S, Pfadenhauer LM, Rohwer AC, van Erp AM, Turley R, Rehfuess E. Interventions to reduce ambient particulate matter air pollution and their effect on health. *Cochrane Database Syst Rev* 2019; 5: CD010919.

205. National Air Quality Index. India. https://app.cpcbccr.com/AQI_India/. Date last accessed: Feb 04, 2019.

206. NASA. Air Quality. https://earthdata.nasa.gov/earth-observation-data/near-real-time/hazards-and-disasters/air-quality. Date last accessed: Feb 04, 2019.

207. London Air Quality Network. London air. http://www.londonair.org.uk/LondonAir/Default.aspx. Date last accessed: Feb 04, 2019.

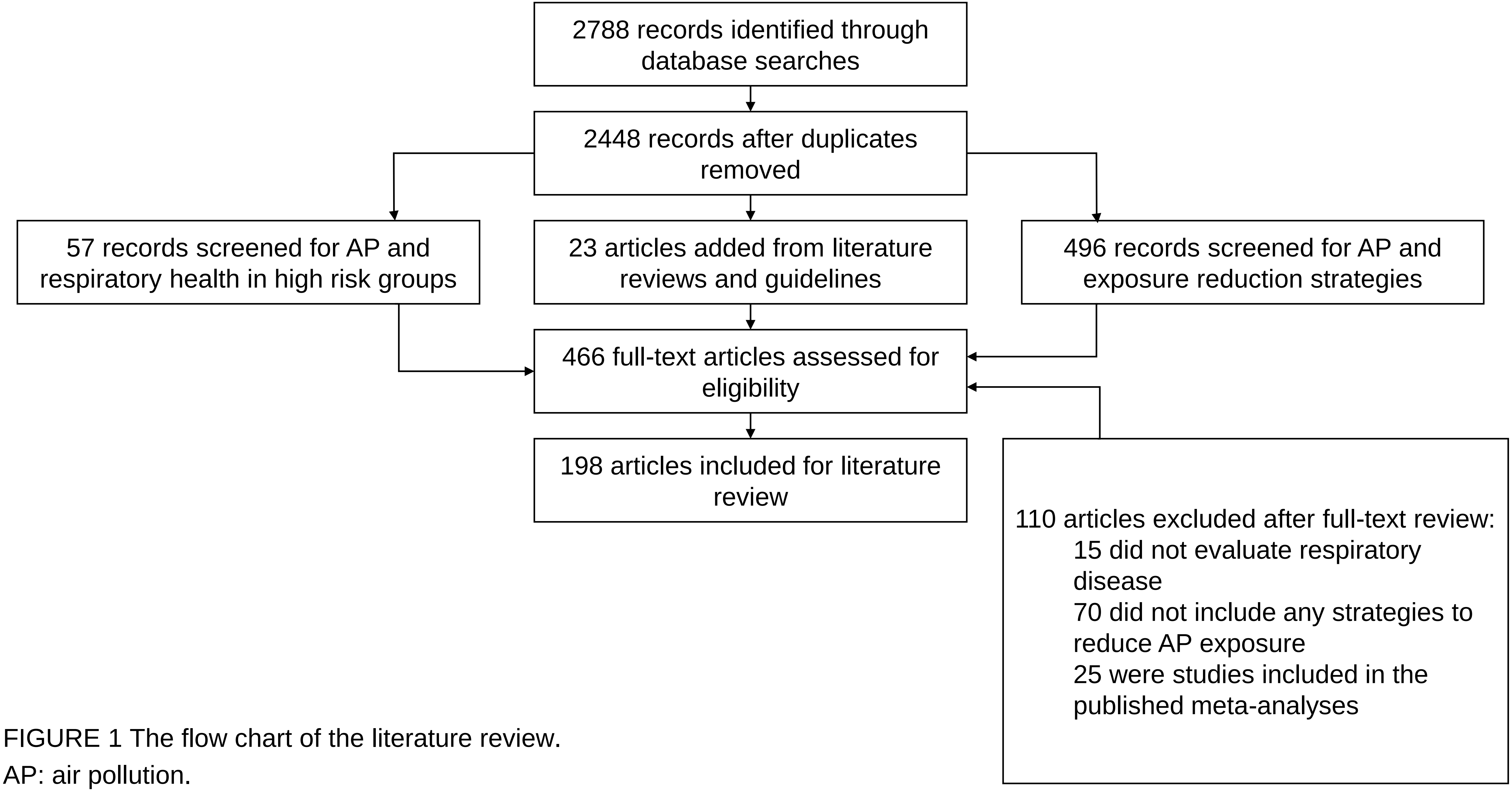

FIGURE 1 The flow chart of the literature review.
AP: air pollution.

OPTIMISE LAND USE AND ACCESS TO GREEN AREAS

Land-use decisions tend not to consider AP-related health impacts, nor do they require minimum distances between sources and individuals. Consequently, residential developments and key community resources (e.g., schools, hospitals) are often located near major traffic arteries [70].

Urban planning of 'smart' cities must also balance the relative benefits and hazards of active travel with increased urban density and TRAP exposure [52].

Minimising the spread of urban developments to decrease dependence on motorised vehicles must be evaluated in the context of increasing urban density and ensuring active travel routes are not located in close proximity to high-traffic streets [41, 70].

The result is that the primary sources of TRAP and the populations with increased susceptibility to AP health effects are often co-located [70].

Designated walking and cycling paths must be separated from motorised traffic where possible to reduce TRAP exposures and promote safety for active commuters [41].

A paper by National Institute for Health and Care Excellence (NICE) on the prioritised quality improvement areas for development relating to AP and health stated that a key area involved improving the relationship between land use planning and transport planning, providing clear spatial principles which direct new development to locations which reduce the need for individual motorised travel, tackle congestion, and improve air quality [52].

City planning should aim to promote physical separation of susceptible subpopulations from AP sources by incorporating community susceptibility profiles as well as knowledge of AP exposure sources such as bus and railway stations, transit corridors, and industrial areas [70].

Rethinking land use could reduce AP exposures for particularly susceptible populations [70].

Urban green space, such as parks, playgrounds, and residential greenery, may promote mental and physical health as well as reduce respiratory morbidity and mortality in residents of urban areas by both reducing exposure to air pollutants and supporting physical activity [71, 72].

FIGURE 2 Community level interventions.
AP: air pollution; TRAP: traffic-related air pollution.

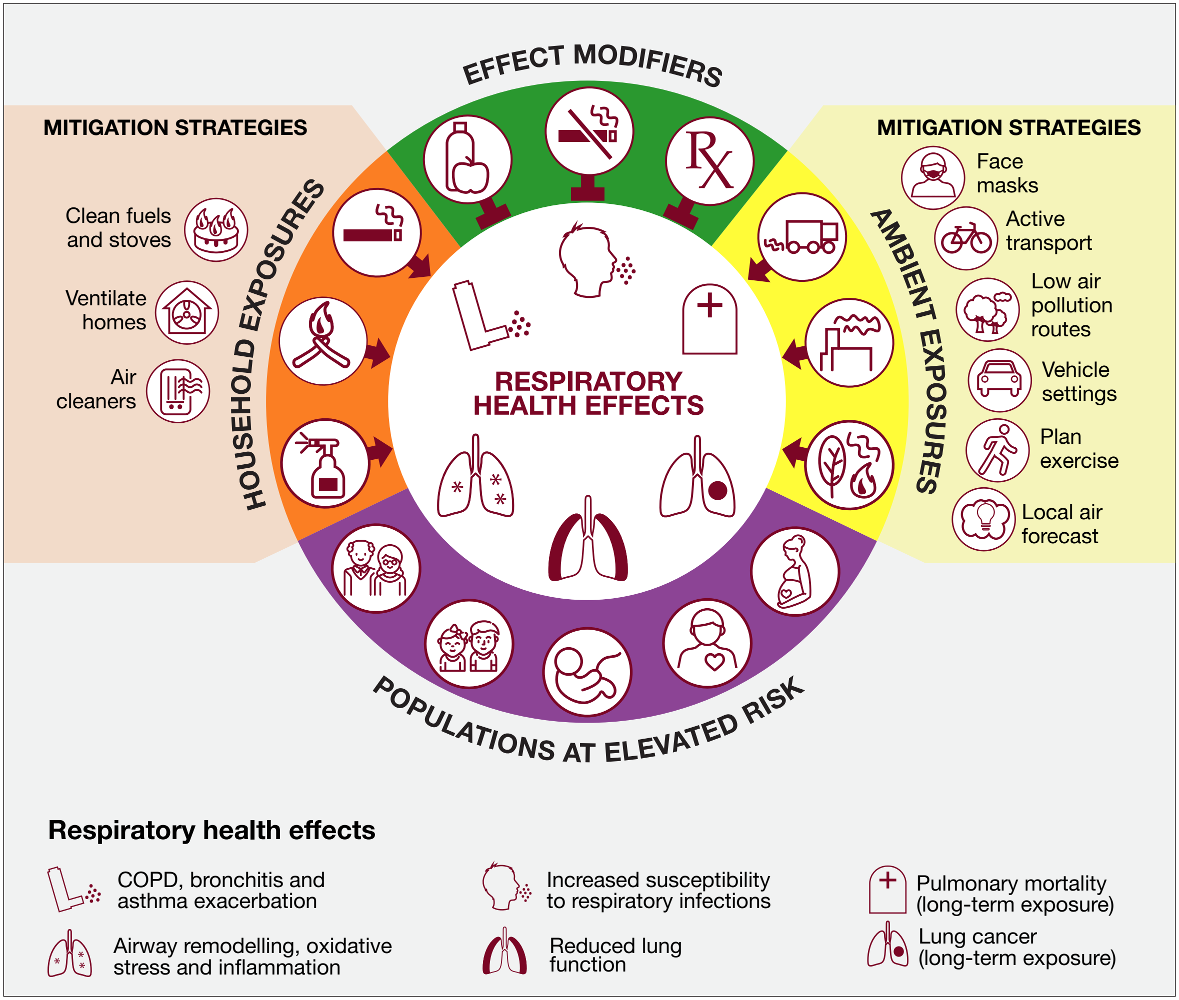

FIGURE 3 Key elements in mitigating air pollution exposure and protecting respiratory health. COPD: chronic obstructive pulmonary disease.

Personal strategies to minimise effects of air pollution on respiratory health: advice for providers, patients and the public

Christopher Carlsten MD[1], Sundeep Salvi PhD, Gary WK Wong MD, Kian Fan Chung MD

1. Corresponding author

Online supplement

SUPPLEMENTARY TABLE 1 Search strategy details.

The search was restricted to references published in English and in humans. In addition to PubMed, the following sources were searched for relevant references: The Global Burden of Disease Study, World Health Organization reports, Royal College of Physicians of London reports, The Lancet Commissions, and guidelines for use of devices designed to reduce levels of air pollution.

Search terms	**Database**	**Number of results**	**Number of relevant articles**
STRATEGIES TO MINIMISE EXPOSURE TO AIR POLLUTION			
Strategies to minimise personal exposure to ambient air pollution			
(air pollution OR particulate matter) AND (masks OR facemasks OR mask OR facemask OR respirator OR respirators OR "barrier methods" OR pollution domes OR pollution dome)	PubMed	120	36
(air pollution OR particulate matter) AND personal protective equipment	PubMed	98	18
(air pollution OR particulate matter) AND (risk reduction behavior OR “behavioral change” OR “behavioural change” OR “behavior change” OR “behaviour change” OR “exposure reduction” OR “exposure reducing”)	PubMed	124	14
"air quality health index" OR "air quality index" AND (exposure OR behavior)	PubMed	48	14
(air pollution OR particulate matter) AND (monitor OR monitors OR phone OR phones OR smartphone OR smartphones OR app) AND “personal exposure”	PubMed	43	13
("wearable sensor" OR "wearable sensors" OR "portable sensor" OR "portable sensors") AND (air pollution OR particulate matter)	PubMed	9	4
(air pollution [Title] OR particulate matter[Title] OR pollutants[Title]) AND (exercise OR physical activity) AND (exposure OR behavior OR behaviour)	PubMed	117	56
(air pollution OR particulate matter) AND (“traffic fumes” OR exhaust OR “traffic exposure” OR “traffic	PubMed	43	4

emissions”) AND personal exposure			
(air pollution OR particulate matter) AND (commute[Title/Abstract] OR commutes[Title/Abstract] OR commuting[Title/Abstract]) AND exposure	PubMed	77	49
(vehicle OR traffic OR car OR vehicles OR cars) AND idling AND (air pollution OR particulate matter)	PubMed	18	6
("traffic-related air pollution" OR "traffic related air pollution") AND (manage OR prevent* OR reduc* OR minimi* OR mitig* OR eliminat* OR interven* OR abrogat*) AND respiratory	PubMed	41	8
(wildfire OR wildfires OR "wild fire" OR "wild fires") AND (air pollution OR particulate matter) AND exposure	PubMed	60	9
(duststorm* OR dust storm* OR “dust storm” OR "dust storms") AND (air pollution OR particulate matter) AND exposure	PubMed	36	4
(air pollution OR particulate matter) AND (“personal exposure” or “individual exposure”) AND (manag*[Title] OR prevent*[Title] OR reduc*[Title] OR minimi*[Title] OR behav*[Title] OR mitigat*[Title])	PubMed	13	3
(air pollution OR particulate matter) AND exposure AND (guideline[Title] OR guidelines[Title] OR guidance[Title] OR advice[Title] OR recommendation[Title] OR recommendations[Title])	PubMed	31	2
Strategies to minimise personal exposure to household air pollution			
(Air pollution) AND (respiratory health) [Title/Abstract]	PubMed	160	60
(air pollut*) OR (particulate matter) OR (particle poll*) AND (air purifier) OR (air filter) OR (nasal filter) OR (air cleaner) OR (ventilation) [Title/Abstract]	PubMed	327	136
(air pollut*) OR (particulate matter) OR (particle poll*) AND (behaviour) OR (behavior) [Title/Abstract]	PubMed	354	17
(air pollut*) OR (particulate matter) OR (particle poll*) AND (monitor) OR (forecast) OR (index) AND (respiratory) [Title/Abstract]	PubMed	121	13
(air pollut*) OR (particulate matter) OR (particle	PubMed	69	18

poll*) AND (fire) OR (coal) OR (cookstove) OR (cook stove) OR (wood stove) OR (woodstove) OR (kerosene) OR (biomass) AND (household) OR (indoor) AND (manag*) OR (prevent*) OR (mitigat*) OR (abrogat*) OR (reduc*) OR (minimi*) OR (eliminat*) OR (interven*) [Title/Abstract]			
(air pollut*) OR (particulate matter) OR (particle poll*) AND (tobacco smoke) OR (cigarette smoke) AND (manag*) OR (prevent*) OR (mitigat*) OR (abrogat*) OR (reduc*) OR (minimi*) OR (eliminat*) OR (interven*) AND (respiratory) [Title/Abstract]	PubMed	148	8
(air pollut*) OR (particulate matter) OR (particle poll*) AND (household) OR (indoor) AND (manag*) OR (prevent*) OR (mitigat*) OR (abrogat*) OR (reduc*) OR (minimi*) OR (eliminat*) OR (interven*) AND (respiratory) [Title/Abstract]	PubMed	149	20
(air pollut*) OR (particulate matter) OR (particle poll*) AND (recommendation) OR (guideline) OR (guidance) OR (best practice) OR (expert opinion) OR (consensus) OR (strategy) AND (manag*) OR (prevent*) OR (mitigat*) OR (abrogat*) OR (reduc*) OR (minimi*) OR (eliminat*) OR (interven*) AND (respiratory) [Title/Abstract]	PubMed	58	14
Strategies to protect those most at risk (e.g. children, older people, and people with chronic health problems/co-morbidities)			
(air pollution OR particulate matter) AND respiratory AND (manage OR prevent* OR reduc* OR minimi* OR mitig* OR eliminat* OR interven* OR abrogat*) AND (children[Title] OR elderly[Title] OR pregnancy[Title] OR "in utero"[Title] OR asthma[Title] OR allergic rhinitis[Title] OR chronic obstructive pulmonary disease[Title] OR genetic counseling[Title] OR infection[Title] OR inflammation[Title] OR "at risk"[Title] OR "susceptible"[Title]]	PubMed	341	57
Effect modifiers, treatments/interventions to minimise exposure/strengthen defence mechanisms			
(Air pollution[Title/abstract] OR particulate matter[Title/abstract]) AND respiratory AND (diet[Title/abstract] OR dietary[Title/abstract] OR antioxidant*[Title/abstract] OR	PubMed	88	22

vitamins[Title/abstract] OR supplements[Title/abstract])			
(Air pollution[Title/abstract] OR particulate matter[Title/abstract]) AND respiratory AND (leukotriene receptor antagonist[Title/abstract] OR antileukotrienes OR salmeterol[Title/abstract] OR albuterol[Title/abstract] OR long-acting bronchodilator[Title/abstract] OR corticosteroid*[Title/abstract] OR anti-inflammatory[Title/abstract] OR chemoprevention[Title/abstract] OR counselling[Title/abstract])	PubMed	36	9
Misconceptions about air pollution and respiratory health			
(Air pollution[Title/abstract] OR particulate matter[Title/abstract]) AND respiratory AND (diet[Title/abstract] OR dietary[Title/abstract] OR antioxidant*[Title/abstract] OR vitamins[Title/abstract] OR supplements[Title/abstract])	PubMed	6	1

*the asterisk at the end of a truncated word is used to search for all terms that begin with the word root.

SUPPLEMENTARY TABLE 2 Description of levels of evidence used in this review (adapted from the levels of evidence used in the GINA guidelines 2019 [1]).

Evidence level	Sources of evidence	Definition
A	RCTs and meta-analyses. Rich body of data.	Evidence is from endpoints of well-designed RCTs, meta-analyses or strong observational evidence that provide a consistent pattern of findings in the population for which the recommendation is made. Category A requires substantial numbers of studies involving substantial numbers of participants.
B	RCTs and meta-analyses. Limited body of data.	Evidence is from endpoints of intervention studies that include only a limited number of patients, post-hoc or subgroup analysis of RCTs, or meta-analysis of such RCTs. In general, Category B pertains when few randomised trials exist, they are small in size, they were undertaken in a population that differs from the target population of the recommendation, or the results are somewhat inconsistent.
C	Non-randomised trials. Observational studies.	Evidence is from outcomes of uncontrolled trials or non-randomised trials or from observational studies.
D	Panel consensus judgement.	This category is used only in cases where the provision of some guidance was deemed valuable but the clinical literature addressing the subject was insufficient to justify assignment of one of the other categories. The Panel Consensus is based on clinical experience or knowledge that does not meet the above listed criteria.

GINA: Global Initiative for Asthma; RCT: randomised controlled trial.

SUPPLEMENTARY TABLE 3 Summary of the key supporting evidence for each recommendation from studies that included at least one respiratory health outcome.

1. **Use facemasks under appropriate circumstances**

Reference	Design	Population, sample size	Key findings
Cherrie et al., 2018 [2]	Non-randomised, non-controlled	Healthy adults in China (n=10)	Four commercial masks were tested on volunteers exposed to diesel exhaust inside an experimental chamber. The facemasks did not provide adequate protection from particles primarily due to poor facial fit.
Guan et al., 2018 [3]	Randomised, controlled, double-blind, crossover	Healthy adults in China (n=15)	N95 facemasks provided some protection against airway inflammation following exposure to traffic-associated particle pollution, but neither systemic oxidative stress nor endothelial dysfunction improved significantly.
Yang et al., 2018 [4]	Randomised, non-controlled, crossover	Healthy adults in China (n=39)	Short-term wearing of N95-like particulate-filtering masks was associated with improved autonomic nervous function. Masks were tested for facial fit.
Shi et al., 2017 [5]	Randomised, non-controlled, crossover	Healthy adults in China (n=24)	Short-term wearing of N95 particulate-filtering masks was associated with improved autonomic nervous function and reduced blood pressure. Masks were tested for facial fit.
Shakya et al., 2016 [6]	Non-randomised, non-controlled	Healthy adults in Nepal (n=53)	N95 facemasks provided a modest but acute improvement in lung function (measured by spirometry) when were worn by traffic officers for just half of a workweek.

2. **Shift from motorised to active transport whenever possible**

Reference	Design	Population, sample size	Key findings
Cepeda et al., 2017 [7]	Systematic review	39 studies (intervention, observational and mixed design) comparing AP exposure according to transport mode	The benefits of physical activity when actively commuting versus using motorised transport outweighed the risks associated with the increased inhaled dose of air pollutants. Commuters using motorised transport were estimated to lose up to 1 year of life expectancy compared with cyclists.
Raza et al., 2018 [8]	Systematic review	18 studies (health impact	Shifts from motorised transport to active travel would reduce traffic volume and

		assessment) comparing AP exposure according to transport mode	related AP emissions thereby contributing small health benefits for the general population overall.
Mueller et al., 2015 [9]	Systematic review	30 studies (health impact assessment) comparing AP exposure according to transport mode	Net health benefits of active travel exceeded detrimental effects of AP exposure and traffic incidents. Older people were estimated to benefit more than younger people due to the increased protection physical activity offers against chronic degenerative disease incidence but may be more vulnerable to traffic incidents when walking and cycling.
Xia et al., 2015 [10]	Health impact assessment	Modelling of AP and comparative risk assessment in Adelaide, Australia, estimated population 1.4 million	Shifting 10% of vehicle kilometres travelled from passenger vehicles to cycling would prevent 321 deaths/year and 4,132 Disability-Adjusted Life Years/year, mainly through a reduction in total disease burden associated with lack of physical activity.
Tainio et al., 2016 [11]	Health impact assessment	Health impact model of AP and physical activity using all-cause mortality as the health outcome	Benefits from active travel generally outweighed health risks from AP. For 30 minutes of cycling every day, the background $PM_{2.5}$ concentration would need to be 95 μg m^{-3} to reach the point above which additional physical activity would not lead to higher health benefits. In the WHO Ambient Air Pollution Database <1% of cities have $PM_{2.5}$ annual concentrations above that level. For 30 minutes of cycling every day the background $PM_{2.5}$ concentration would need to be 160 μg m^{-3} to reach the point above which additional physical activity would cause adverse health effects. The average urban background $PM_{2.5}$ concentration in the WHO database was 22 μg m^{-3} and the point above which additional physical activity would cause adverse health effects would only be reached after 7 hours of cycling and 16 hours of walking per day. In a highly polluted city such as Delhi with background $PM_{2.5}$ concentrations of 153 μg m^{-3}, up to 30 minutes of cycling and 6 hours 15 minutes of walking per day

			would lead to a net reduction in all-cause mortality versus staying at home (i.e. background $PM_{2.5}$ concentration).
Andersen et al., 2015 [12]	Epidemiological study	Subjects (n=52,061; 50–65 years old) from the Danish Diet, Cancer and Health cohort living in Aarhus and Copenhagen, reported data on physical activity in 1993–1997 and were followed to 2010	Benefits from physical activity during cycling generally outweighed health risks from AP. There was a statistically significant inverse association between cycling and all-cause mortality (HR 0.83; 95% CI 0.78, 0.88), and cycling and respiratory mortality (HR 0.62; 95% CI 0.5, 0.77). Long-term benefits of physical activity on mortality were not moderated by exposure to high levels of NO_2 defined as ≥19.0 µg m^{-3} NO_2.
Gaffney et al., 2016 [13]	Cross-sectional population-based study	Adults in Shanghai, China (n=20,102)	Commuting by walking and by bus but not by car was associated with small but statistically significant reductions in pulmonary function (FEV_1 and FVC) compared with cycling (p<0.01).

3. Choose travel routes that minimise near-road AP exposure

Reference	Design	Population, sample size	Key findings
Jarjour et al., 2013 [14]	Non-randomised, non-controlled comparative study	Healthy adults in California, US (n=15)	Subjects were exposed to lower BC, UFP, and CO levels on a single commute (8.0–9.5 km) by bicycle on a low-traffic versus a high-traffic route (p<0.06). However, no significant differences in lung function (measured by spirometry) were observed.
Park HY et al., 2017 [15]	Non-randomised, non-controlled	Healthy adults in Brisbane, Australia (n=32)	Short-term increases in UFPM levels (used as proxy for near-road TRAP) were associated with decreased lung function when cycling (22.2 km) versus baseline. Lung function decrements (FVC and FEV_1) were greater in cyclists using high traffic versus low traffic routes (p<0.005); cyclists should plan their route to reduce exposures.
Sinharay et al., 2018 [16]	Randomised, crossover	Adults aged ≥60 years old with COPD (n=40), ischemic heart disease (n=39) and aged-matched healthy	Concentrations of BC, NO_2, $PM_{2.5}$, PM_{10}, and UFPs were greater on the high traffic versus the low traffic route (p<0.001). Participants with COPD reported higher scores for respiratory symptoms after walking down the high traffic versus low traffic route (p<0.05).

		volunteers (n=40) in London, UK	Improvements in lung function (FVC and FEV_1) were observed in healthy subjects and those with COPD after walking down the low traffic but not the high traffic route versus baseline. The findings suggest that older individuals and adults with chronic cardiorespiratory disorders should minimise walking on streets with high levels of pollution because this negates the cardiorespiratory benefits of exercise.

4. **Optimise driving style and vehicle settings**

Reference	Design	Population, sample size	Key findings
Yu et al., 2017 [17]	Non-randomised, non-controlled	Taxi drivers (n=17), mean age 47 years old, in Los Angeles, US	Driving with windows closed and using a high efficiency cabin air filter reduced $PM_{2.5}$ and UFP levels inside the vehicles by 37% and 47%, respectively ($p<0.05$) and reduced drivers urinary MDA concentrations by 17% (not significant) versus no intervention. Urinary MDA levels were used as a marker of systematic oxidative stress induced by in-vehicle PM exposure; however, there was a lack of clinical studies assessing health outcomes.

5. **Moderate outdoor physical activity when and where AP levels are high**

Reference	Design	Population, sample size	Key findings
Sinharay et al., 2018 [16]	randomised, crossover	Adults aged ≥60 years old with COPD (n=40), ischemic heart disease (n=39) and aged-matched healthy volunteers (n=40) in London, UK	Adults with COPD, who walked for 2 hours on a traffic-polluted road were found to have more cough ($p<0.1$), sputum ($p<0.05$), shortness of breath ($p<0.1$) and wheeze ($p<0.05$) versus walking in a traffic-free area. A reduction in lung function from baseline was associated with an increase in during-walk exposure to NO_2, UFP, and $PM_{2.5}$. The beneficial effects of physical activity on respiratory/pulmonary measures were attenuated in healthy adults and those with COPD when exposed to high versus low AP levels.
Lamichhane et al., 2018 [18]	Non-randomised, non-controlled,	Adults (n=1264), mean age 58 years	Although not significant, the negative effect of $PM_{2.5}$ on lung function (measured by spirometry) was greater

	cross sectional	old, with suspected COPD or asthma in South Korea	among those who did not exercise versus those that did.
Zhang et al., 2018 [19]	Prospective, longitudinal cohort	Adults (n=359,067), mean age 40 years old at start, in Taiwan	Regular exercise was associated with lower markers of systemic inflammation (indicated by white blood cell counts) than inactivity at all levels of $PM_{2.5}$ exposure (<21.7 µg m^{-3} to ≥28.1 µg m^{-3}) ($p<0.001$). High levels of physical activity had greater beneficial effects at all levels of $PM_{2.5}$ exposure versus moderate or low levels of physical activity ($p<0.001$).
Andersen et al., 2015 [12]	Epidemiological	Adults (n=52,061) aged 50–65 years old from the Danish Diet, Cancer, and Health cohort, living in Aarhus and Copenhagen	Inverse associations were observed between cycling and respiratory mortality ($p=0.09$) and this was stronger among subjects with NO_2 exposure <19.0 µg m^{-3} (HR=0.55; 95% CI: 0.42, 0.72) than those with high NO_2 exposure ≥19.0 µg m^{-3} (HR=0.77; 95% CI: 0.54, 1.11). Cycling in areas with high versus moderate/low levels of AP reduced, but did not reverse, the benefits of physical activity on respiratory mortality.
Fisher et al., 2016 [20]	Epidemiological	Adults (n=53,113) aged 50–65 years old from the Danish Diet, Cancer, and Health cohort, living in Aarhus and Copenhagen	The beneficial effects of doing sports, cycling, and gardening in reducing risk of new asthma and COPD hospitalisations were not moderated in subjects who lived in areas with high NO_2 levels ≥21.0 µg m^{-3} versus those in areas with low NO_2 levels <14.3 µg m^{-3}, despite positive associations between NO_2 and incident asthma/COPD hospitalisations. Increased exposure to NO_2 did not outweigh the beneficial effects of physical activity for reducing risk of hospitalisation for asthma and COPD.
Matt et al., 2016 [21]	Real-world, non-randomised, crossover	Healthy adults (n=30) in Barcelona, Spain	Individuals had a short-term increase in lung function (spirometry) for several hours after physical activity even in highly-polluted environments. However, high TRAP versus low TRAP exposure attenuated the immediate respiratory benefits of physical activity.
Kubesch et al., 2015 [22]	Real-world, non-	Healthy adults (n=28) in	Intermittent moderate physical activity (15-minute intervals of alternating rest

	randomised, crossover	Barcelona, Spain	and cycling on a stationary bicycle) increased pulmonary function at low and high TRAP levels versus rest ($p \leq 0.05$).
Laeremans, 2018 [23]	Real-world, non-randomised, crossover	Healthy adults (n=122) in three European cities	Physical activity increased lung function versus baseline (FEV_1: +15.63 mL; $p<0.05$), while exposure to BC was associated with a decrease in lung function (PEF: −0.10 mL; $p<0.05$). An interaction between physical activity and BC on lung function ($p<0.05$) suggested a potential protective effect of physical activity against the negative effects of AP on lung function.

6. **Monitor AP levels**

Reference	Design	Population, sample size	Key findings
Stergiopoulou et al., 2018 [24]	Epidemiological	Children (n=97) aged 10–11 years old in Athens, Greece	Higher O_3 concentrations indicated by the local O_3 AQI were associated with increased daily occurrence of respiratory symptoms cough and nasal congestion; however, the study did not investigate whether knowledge of the AQI was associated with reduced incidence of respiratory symptoms.

7. **Use clean fuels, ensure adequate household ventilation where possible, and adopt improved cookstoves where resources remain sufficient**

Reference	Design	Population, sample size	Key findings
Choi et al., 2015 [25]	Real-world, non-randomised, non-crossover	Adult females (n=547), aged 18–85 years and children (n=845) ages 0–17 years in households exclusively cooking with either kerosene or LPG in Bangalore, India	In women, cooking with kerosene was associated with cough (OR=1.88; $p<0.01$) and chest illness (OR=1.61; $p<0.05$), relative to cooking with LPG in the multivariate models. In children, living in a household cooking with kerosene was associated with bronchitis (OR=1.91; $p<0.05$) and phlegm (OR=2.20; $p<0.01$) after adjusting for other covariates.
Lamichhane et al., 2017 [26]	Survey	Children (n=16,157) aged <5 years in India	In rural households use of LPG was associated with 10.7% lower probability of ARI versus exclusive use of polluting fuels.

Lewis et al., 2017 [27]	Cross-sectional observational cohort	Households (n=105) in Odisha, India	Use of improved (electric or gas) cookstoves was associated with a 72% reduction in $PM_{2.5}$, a 78% reduction in Polycyclic aromatic hydrocarbons levels, and reductions in water-soluble organic carbon and nitrogen compared with traditional mud stoves ($p<0.01$). Improved cookstove use was associated with shorter hospital stays for ARI compared with traditional mud stoves ($p<0.10$).
Downward et al., 2018 [28]	Cross-sectional observational	Female bakery workers (n=35) aged 18–60 years in Addis Ababa, Ethiopia	Biomass cookstoves were associated with higher exposure to $PM_{2.5}$ and CO versus electric cookstoves ($p<0.05$), and greater odds of reporting stopping for breath when walking (OR: 6.9; 95% CI: 1.3, 52.8).
Yu et al., 2018 [29]	Prospective cohort	Adults (n=271,217), mean age 51 years in rural China	Adults who switched from solid fuels to clean fuels (electric or gas) for cooking or who used ventilation when cooking had a lower risk of all-cause mortality than persistent solid fuel users or those who reported no ventilation during cooking (HR: 0.87; 95% CI: 0.79, 0.95 and HR: 0.91; 95% CI: 0.85, 0.96), respectively. Adults with longer self-reported duration of solid fuel use for cooking and heating had higher risks of all-cause mortality ($p<0.001$) than those with shorter duration.
Mortimer et al., 2017 [30]	Open cluster RCT	Children (n=10,453), aged <5 years in rural Malawi	Cleaner burning biomass-fuelled cookstoves did not reduce the risk of pneumonia in young children versus open fire cooking over a 2-year period.
Noonan et al., 2017 [31]	RCT	Children with asthma (n=114), mean age 12·4 years in three US states	Use of improved-technology wood-burning appliances did not reduce indoor $PM_{2.5}$ levels or improve Paediatric Asthma Quality of Life Questionnaire scores relative to placebo in children with asthma who were chronically exposed to wood smoke; however, use of an air filtration device reduced indoor PM levels by 67% and improved the secondary measured dPFV by 11.8% versus baseline, an indirect measure of airway hyper-responsiveness.
Guarnieri et al., 2015 [32]	Longitudinal, randomised cohort	Women (n=265) in Guatemala	No association between lung function parameters in women measured by spirometry (PEF and FEV_1) following

			an early stove intervention with improved ventilation versus a delayed stove intervention; however, individuals had continued heavy smoke exposure despite reductions associated with the improved cookstoves.
Heinzerling et al., 2016 [33]	Longitudinal, randomised cohort	Children (n=880), aged 5–8 years in Guatemala	Decreases in PEF growth of 173 mL/min/year (95% CI: −341, −7; p=0.041) and FEV_1 of 44 mL/year (95% CI: −91, 4, p=0.07) were observed in children whose families did not receive a chimney stove until 18 months of life versus stove installation at birth in analyses adjusted for multiple covariates. No associations were observed between personal household AP exposure and lung function; individuals had continued heavy smoke exposure despite reductions associated with the improved cookstoves.
Quansah et al., 2017 [34]	Systematic review and meta-analysis	Systematic review (n=55 studies); meta-analysis of experimental studies (n=15 studies)	There was limited evidence that improving cookstoves in homes using solid fuel in low- and middle-income countries yielded any health benefits despite reducing personal exposures to PM and CO.
Thakur et al., 2018 [35]	Systematic review and meta-analysis	(Quasi-)experimental studies (n=29); longitudinal observational studies (n=29)	Improved cookstove efficiency or ventilation was associated with reduced respiratory symptoms (cough, phlegm, wheezing/breathing difficulty) and a reduction in COPD among women versus use of traditional cookstoves; no demonstrable child health impact was observed.
Das et al., 2018[36]	Survey	Children (n=694) aged <5 years in Gisenyi, Rwanda	Outdoor cooking areas were associated with fewer symptoms of respiratory infection (p<0.05), illness with cough (p<0.1) and difficulty breathing (p<0.05) in children compared with enclosed dwellings. Ventilation was associated with fewer symptoms of illness with cough (p<0.01) and difficulty breathing (p<0.01) versus no ventilation in the cooking area.
Accinelli et al., 2014 [37]	Prospective survey	Children (n=82) aged 2–14 years in Andahuaylas province in Peru	Sleep-related problems, sore throat and headache improved in children following a switch from traditional stoves to improved kitchen stoves (p<0.05). Improved stoves with external

			exhausts were found to reduce PM concentrations by 74%.
Castañeda et al., 2013 [38]	Prospective survey	Children (n=59) aged <15 years in Cangallo province in Peru	Implementation of stoves with external exhausts in homes reduced nasal congestion (33.9% versus 1.8%, $p<0.0001$), sore throat (38.2% versus 5·5%, $p<0.0001$), breathing through the mouth during the day (33.9% versus 1.8%, $p<0.001$) as well as sleep-related symptoms versus traditional wood-burning stoves.
Seow et al., 2014 [39]	Review of case-control and cohort studies	Adults in Xuanwei, China	The installation of a chimney in homes reduced lung cancer incidence and mortality, lowered COPD incidence and reduced incidence of pneumonia by 50%, for both men and women, and for users of both smoky and smokeless coal.
Kim et al., 2015 [40]	Prospective cohort	Women (n=71,320) in Shanghai, China	Coal use in poorly ventilated kitchens was associated with a 49% increased risk of lung cancer (HR: 1.49; 95% CI: 1.15, 1.95), and the strength of association increased with years of exposure. Women who had lived in a home with poor ventilation during childhood and adulthood had a 69% increased risk of lung cancer versus women never exposed to poor ventilation during their lives (HR: 1.69; 95% CI: 1.22, 2.35).
Jin et al., 2014 [41]	Population-based, case-control	Subjects with lung cancer (n=1,424) and healthy controls (n=4,543) in Jiangsu Province, China	Good ventilation of households was associated with lung cancer risk reduction versus poor ventilation (OR: 0.87; 95% CI: 0.75, 1.00) and use of coal for cooking was associated with an increased lung cancer risk versus not using coal (OR: 1.27; 95% CI: 1.10, 1.47).
Mu et al., 2013 [42]	Population-based, case-control	Adults with lung cancer (n=399) and healthy controls (n=466) in Taiyuan, China	Housing characteristics related to poor ventilation, including single-story, less window area, no separate kitchen, no ventilator and rarely having windows open, were associated with increased risk of lung cancer. Every 10 ug m^{-3} increase in PM_1 was associated with 45% increased risk of lung cancer ($p<0.01$).
Hu et al., 2014 [43]	Survey	Adults (n=163) in Xuanwei and Fuyuan, China	$PM_{2.5}$ levels were 34–80% lower among vented stoves compared with unvented stoves and firepits, which paralleled the

			observation of reduced risks of malignant and non-malignant lung diseases in the region.
Zhou Y et al., 2014 [44]	Nine-year prospective cohort	Adults (n=996) aged ≥40 years in Yunyan, Southern China	Replacing biomass with biogas for cooking and improving kitchen ventilation was associated with improved indoor air quality, a reduced decline of lung function and reduced spirometry-measured COPD incidence (OR: 0.28; 95% CI: 0.11, 0.73). The longer the duration of use of improved fuel and ventilation, the slower the decline in FEV_1 ($p<0.05$).
Liu F et al., 2014 [45]	Cross-section	Children (n=23,326) aged 6–13 years in Northeast China	The use in a household of any of the following ventilation devices: exhaust fan, chimney, or fume hood (typically above a cookstove) was associated with decreased odds of asthma as well as decreased prevalence of persistent cough ($p<0.01$) and persistent phlegm ($p<0.05$) versus no ventilation device use.
Langbien, 2017 [46]	Review of 41 surveys	Children aged <5 years in 30 developing countries from Asia, Africa and Latin America	Outdoor cooking was associated with a decrease in ARI occurrence of 9% for children aged 0–4 years and 13% for children aged 0–1 year versus indoor cooking ($p<0.01$).
Kile, 2014 [47]	Cross-sectional survey	Children (n=12,570) aged 2–16 years in the US	Children whose parents reported using ventilation when operating their gas stove had higher lung function and lower odds of asthma (OR: 0.64; 95% CI: 0.43, 0.97), wheeze, (OR: 0.60, 95% CI: 0.42, 0.86), and bronchitis (OR: 0·60, 95% CI: 0.37, 0.95) compared with households that did not have ventilation or where no ventilation was used.
Lajoie et al., 2015 [48]	RCT	Children with asthma (n=83) aged 2–16 years in Canada	Improved ventilation via a mechanical ventilation system reduced episodes of wheezing in children and reduced levels of formaldehyde versus no intervention.
Salvi et al., 2016 [49]	Cross-sectional survey	Households using MC (n=153) in India	Burning of MCs produced indoor levels of $PM_{2.5}$ (up to 1031 μg m^{-3}) and CO (up to 6.50 parts per million) that were higher than those reported during the burning of biomass fuels for cooking purposes. Levels were reduced by improving ventilation, ~50% when the window was opened and >90% when

			both the window and the door were opened. There was a higher prevalence of respiratory symptoms and self-reported respiratory and allergic diseases among those using MCs; however, the values did not reach statistical significance.

8. Use portable air cleaners as an indoor environmental intervention

Reference	Design	Population, sample size	Key findings
Chen R et al., 2015 [50]	RCT	Healthy adults (n=35) in Shanghai, China	Air filter use in dormitories for 48 hours reduced $PM_{2.5}$ concentration by 57% on average versus sham-filter. Fractional exhaled nitrous oxide was reduced by 17% versus sham filter but no significant improvement in lung function was observed.
Cui et al., 2018 [51]	Randomised, blind, crossover intervention	Healthy adults and children (n=70), aged 10–26 years in Shanghai, China	A single overnight residential air filtration using a portable air cleaner with a HEPA filter and activated carbon, reduced indoor $PM_{2.5}$ concentrations by 72% versus sham-filtration and improved airway mechanics but no significant improvements for spirometry indicators (FEV_1, FVC) were observed.
Shao et al., 2017 [52]	Randomised, blind, crossover intervention	Older adults with COPD (n=20), mean age 67 years, and without COPD (n=15), mean age 66 years in Beijing, China	Use of HEPA filters with activated carbon in living room and bedroom areas for 2 weeks reduced $PM_{2.5}$ by 60% and BC by 53% versus sham-filter but no significant changes were observed in the cardiorespiratory outcomes of the participants.
Karottki et al., 2013 [53]	Randomised, double-blind crossover intervention	Older adults (n=48), aged 51–81 years, in Greater Copenhagen, Denmark	Use of HEPA filters in living room and bedroom areas for 2 weeks reduced $PM_{2.5}$ by ~50% versus sham-filter. No differences were found in lung function measures or lung cell damage markers versus sham-filter.
Peng et al., 2015 [54]	Stratification of a randomised intervention trial	Children with asthma (n=75), aged 6-12 years in Baltimore, US	Among children for whom the air cleaner with HEPA filter reduced indoor PM concentrations by an average of 18.4 ug m^{-3}, the intervention resulted in an increase of 2 asthma symptom-free days versus no intervention.
Hackstadt, 2014 [55]	Stratification of a randomised intervention	Children with asthma (n=75), aged 6–12 years	Among children for whom the air cleaner with HEPA filter reduced indoor PM concentrations, the intervention

	trial	in Baltimore, US	resulted in an improvement in asthma symptoms versus no intervention.
Jia-Ying, 2018 [56]	Non-randomised, non-crossover	Adults and children with allergic rhinitis (n=32), aged 4–61 years in Guangzhou, China	HEPA filter air cleaners were placed in bedroom for 4 months. House dust mite allergen concentration was reduced in the indoor air ($p<0.05$) as well as PM_{10}, $PM_{2.5}$ and PM_1 ($p<0.01$) versus baseline. HEPA filtration was associated with improvements in activity limitation and nasal symptoms ($p<0.001$) versus baseline.
Park HK et al., 2017 [57]	Randomised, non-crossover	Children with asthma and/or allergic rhinitis (n=17), aged 6–18 years in California, US	HEPA filter air cleaners with activated carbon were placed in the living room and bedroom for 12 weeks. Indoor $PM_{2.5}$ levels were reduced by 43% and there was an improvement in asthma control scores ($p=0.041$) and PEF ($p=0.037$) over the duration as well as total nasal symptoms scores at Week 12 ($p=0.011$) as well as in the intervention group versus the non-intervention group.
Weichenthal et al., 2013 [58]	RCT	Adults and children (n=37) aged 11–64 years at a First Nation reserve in Canada	On average, air filter use was associated with a 217 mL (95% CI: 23, 410; $p<0.05$) increase in FEV_1 versus placebo filter. Despite reductions of >40% in indoor concentrations of PM with use of a portable air cleaner for 3 weeks, the levels remained higher than outdoors because of a high prevalence of indoor smoking.

9. **Treat and manage respiratory conditions**

Reference	Design	Population, sample size	Key findings
Mirabelli, 2015 [59]	Epidemiologic analysis	Adults with self-reported asthma (n=18) and adults without self-reported asthma (n=21) in Atlanta, US	An analysis from the Atlanta Commuter Exposure study found that an individual's level of asthma control (evaluated using the 7-item Asthma Control Questionnaire) influenced respiratory response to in-vehicle exposures during a 2-hour rush-hour commute; the largest postcommute increases in exhaled NO occurred in participants with below-median asthma control, and higher $PM_{2.5}$ was associated with lower FEV_1 % predicted in this group.

Hasunuma et al., 2018 [60]	Case-crossover design	Children with asthma (n=71) and children without asthma (n=138) in Japan	Exacerbation of respiratory signs and symptoms (% max PEF and coughing) was greater in those children who were not using long-term medications.
Maikawa et al., 2016 [61]	Observational study	Children with asthma (n=62), aged 8–12 years, in Montreal, Canada	FeNO was used as a predictor of airway inflammation. Children with asthma not using corticosteroid medications experienced the greatest increase in FeNO per interquartile range increase of $PM_{2.5}$ oxidative burden versus children using the medication regularly.
Evans et al., 2014 [62]	Case-crossover design	Children with asthma (n=74), aged 3–10 years, in the US	The effects of UFPs and CO on asthma exacerbation were greater among children receiving preventive asthma medications (through a school-based asthma therapy trial) than among those receiving usual care; medication adherence alone may be insufficient to protect this vulnerable group.
Ierodiakonou et al., 2016 [63]	Randomised, longitudinal, observational	Children with asthma (n=1,003), aged 5–12 years, in North America	Daily use of asthma controller medications (budesonide and nedocromil versus placebo) augmented the negative short-term effect of CO on airway responsiveness.

10. **Modify diet and supplement with antioxidants or anti-inflammatory agents**

Reference	Design	Population, sample size	Key findings
Barchitta et al., 2018 [64]	Cross-sectional	Healthy women (n=299), aged 15–80 years, in Catania, Italy	There was an inverse association between adherence to Mediterranean diet and exposure to PM_{10} with LINE-1 methylation; higher monthly PM_{10} exposure decreased LINE-1 methylation level ($p=0.037$), the adherence to Mediterranean diet increased it ($p<0.001$). Mediterranean diet may reduce aberrant DNA methylation, associated with cancer and cardiovascular disease, following PM exposure.
Steinemann et al., 2018 [65]	Epidemiological	Adults (n=2,178), aged 18–60 years, in Switzerland	A diet rich in fruit, vegetables, fish, and nuts was positively associated with FEV_1 ($p<0.001$).
Egner et al., 2014 [66]	RCT	Healthy adults (n=267), aged 21–65 years, in Qidong, China	Consumption of a broccoli sprout beverage consistently increased the excretion of the glutathione-derived conjugates of benzene and acrolein

			($p \leq 0.01$) over a 12-week period suggesting intervention with broccoli sprouts enhanced the detoxication of some airborne pollutants.
Heber et al., 2014 [67]	Controlled, non-randomised	Healthy adults (n=29) positive for cat allergens, aged ≤18 years, in Los Angeles, US	Average nasal WBC counts increased by 85% over the control levels 24 hours after DEP exposure and total cell counts decreased by 54% when DEP challenge was preceded by daily broccoli extract administration for 4 days ($p<0.001$), suggesting broccoli extracts attenuated nasal allergic response to DEP in atopic individuals with baseline airway DEP hypersensitivity.
Hansell et al., 2018 [68]	Cohort, secondary cross-sectional analysis	Children (n=400), aged 8 years, in New South Wales, Australia	Children were randomised to fish oil supplementation or placebo from early life to 5 years of age. Fish oil supplementation protected against the effect of TRAP exposure on pre-bronchodilator FEV_1/FVC ratio versus no supplementation ($p=0.031$) in children who did not move home between age 5 and 8 years.
Tong, 2016 [69]	Review	RCTs and panel studies mainly in healthy adults	In some RCTs, dietary supplementation with vitamins C and E reduced lung function decrements and bronchoconstriction induced by short-term exposure to O_3, SO_2, and PM; and reduced airway inflammation and improved lung function in ozone-exposed patients with asthma.
Carlsten et al., 2014 [70]	RCT	Healthy adults (n=26), aged ≤18 years, in Vancouver, Canada	Pre-treatment with N-acetylcysteine (600 mg, t.i.d.) versus placebo for 6 days abrogated DEP-induced airway responsiveness in participants with baseline airway hyperresponsiveness.

AP: air pollution; AQI: air quality index; ARI: acute respiratory infection; BC: black carbon; CI: confidence interval; CO: carbon monoxide; COPD: chronic obstructive pulmonary disease; DEP: diesel exhaust particles; dPFV: diurnal peak flow variability; FeNO: fractional exhaled nitric oxide; FEV_1: forced expiratory volume in 1 second; FVC: forced vital capacity; HEPA: high efficiency particulate air; HR: hazard ratio; IL-8: interleukin-8; LINE-1: long interspersed nucleotide elements 1; LPG: liquid petroleum gas; MC: mosquito coils; MDA: malondialdehyde; NO: nitric oxide; NO_2: nitrogen dioxide; O_3: ozone; OR: odds ratio; PEF: peak expiratory flow; PM: particulate matter; PNC: particle number concentration; RCT: randomised controlled trial; SO_2: sulphur dioxide; t.i.d.: three times a day; TRAP: traffic-related air pollution; UFP: ultrafine particles; UFPM: ultrafine particulate matter; UK: United Kingdom; US: United States; WBC: white blood cells; WHO: World Health Organization.

References for supplementary material

1. Global Initiative for Asthma. Global Strategy for Asthma Management and Prevention, 2019. https://ginasthma.org/wp-content/uploads/2019/06/GINA-2019-main-report-June-2019-wms.pdf. Date last accessed: Oct 09, 2019.

2. Cherrie JW, Apsley A, Cowie H, Steinle S, Mueller W, Lin C, Horwell CJ, Sleeuwenhoek A, Loh M. Effectiveness of face masks used to protect Beijing residents against particulate air pollution. *Occup Environ Med* 2018; 75: 446–452.

3. Guan T, Hu S, Han Y, Wang R, Zhu Q, Hu Y, Fan H, Zhu T. The effects of facemasks on airway inflammation and endothelial dysfunction in healthy young adults: a double-blind, randomized, controlled crossover study. *Part Fibre Toxicol* 2018; 15: 30.

4. Yang X, Jia X, Dong W, Wu S, Miller MR, Hu D, Li H, Pan L, Deng F, Guo X. Cardiovascular benefits of reducing personal exposure to traffic-related noise and particulate air pollution: a randomized crossover study in the Beijing subway system. *Indoor Air* 2018; 28: 777–786.

5. Shi J, Lin Z, Chen R, Wang C, Yang C, Cai J, Lin J, Xu X, Ross JA, Zhao Z, Kan H. Cardiovascular benefits of wearing particulate-filtering respirators: a randomized crossover trial. *Environ Health Perspect* 2017; 125: 175–180.

6. Shakya KM, Rupakheti M, Aryal K, Peltier RE. Respiratory effects of high levels of particulate exposure in a cohort of traffic police in Kathmandu, Nepal. *J Occup Environ Med* 2016; 58: e218–e225.

7. Cepeda M, Schoufour J, Freak-Poli R, Koolhaas CM, Dhana K, Bramer WM, Franco OH. Levels of ambient air pollution according to mode of transport: a systematic review. *Lancet Public Health* 2017; 2: e23–e34.

8. Raza W, Forsberg B, Johansson C, Sommar JN. Air pollution as a risk factor in health impact assessments of a travel mode shift towards cycling. *Glob Health Action* 2018; 11: 1429081.

9. Mueller N, Rojas-Rueda D, Cole-Hunter T, de Nazelle A, Dons E, Gerike R, Götschi T, Int Panis L, Kahlmeier S, Nieuwenhuijsen M. Health impact assessment of active transportation: A systematic review. *Prev Med* 2015; 76: 103–114.

10. Xia T, Nitschke M, Zhang Y, Shah P, Crabb S, Hansen A. Traffic-related air pollution and health co-benefits of alternative transport in Adelaide, South Australia. *Environ Int* 2015; 74: 281–290.

11. Tainio M, de Nazelle AJ, Götschi T, Kahlmeier S, Rojas-Rueda D, Nieuwenhuijsen MJ, de Sá TH, Kelly P, Woodcock J. Can air pollution negate the health benefits of cycling and walking? *Prev Med* 2016; 87: 233–236.

12. Andersen ZJ, de Nazelle A, Mendez MA, Garcia-Aymerich J, Hertel O, Tjønneland A, Overvad K, Raaschou-Nielsen O, Nieuwenhuijsen MJ. A study of the combined effects of physical activity and air pollution on mortality in elderly urban residents: the Danish diet, cancer, and health cohort. *Environ Health Perspect* 2015; 123: 557–563.

13. Gaffney AW, Hang J-Q, Lee M-S, Su L, Zhang F-Y, Christiani DC. Commuting mode and pulmonary function in Shanghai, China. *Eur Respir J* 2016; 47: 733–741.

14. Jarjour S, Jerrett M, Westerdahl D, de Nazelle A, Hanning C, Daly L, Lipsitt J, Balmes J. Cyclist route choice, traffic-related air pollution, and lung function: a scripted exposure study. *Environ Health* 2013; 12: 14.

15. Park H-Y, Gilbreath S, Barakatt E. Respiratory outcomes of ultrafine particulate matter (UFPM) as a surrogate measure of near-roadway exposures among bicyclists. *Environ Health* 2017; 16: 6.

16. Sinharay R, Gong J, Barratt B, Ohman-Strickland P, Ernst S, Kelly FJ, Zhang J, Collins P, Cullinan P, Chung KF. Respiratory and cardiovascular responses to walking down a traffic-polluted road compared with walking in a traffic-free area in participants aged 60 years and older with chronic lung or heart disease and age-matched healthy controls: a randomised, crossover study. *Lancet* 2018; 391: 339–349.

17. Yu N, Shu S, Lin Y, She J, Ip HSS, Qiu X, Zhu Y. High efficiency cabin air filter in vehicles reduces drivers' roadway particulate matter exposures and associated lipid peroxidation. *PLoS One* 2017; 12: e0188498.

18. Lamichhane DK, Leem JH, Kim HC. Associations between ambient particulate matter and nitrogen dioxide and chronic obstructive pulmonary diseases in adults and effect modification by demographic and lifestyle factors. *Int J Environ Res Public Health* 2018; 15: 363.

19. Zhang Z, Hoek G, Chang L-Y, Chan T-C, Guo C, Chuang YC, Chan J, Lin C, Jiang WK, Guo Y, Vermeulen R, Yeoh E-k, Tam T, Lau AKH, Griffiths S, Lao XQ. Particulate matter air pollution, physical activity and systemic inflammation in Taiwanese adults. *Int J Hyg Environ Health* 2018; 221: 41–47.

20. Fisher JE, Loft S, Ulrik CS, Raaschou-Nielsen O, Hertel O, Tjønneland A, Overvad K, Nieuwenhuijsen MJ, Andersen ZJ. Physical activity, air pollution, and the risk of asthma and chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2016; 194: 855–865.

21. Matt F, Cole-Hunter T, Donaire-Gonzalez D, Kubesch N, Martínez D, Carrasco-Turigas G, Nieuwenhuijsen M. Acute respiratory response to traffic-related air pollution during physical activity performance. *Environ Int* 2016; 97: 45–55.

22. Kubesch NJ, de Nazelle A, Westerdahl D, Martinez D, Carrasco-Turigas G, Bouso L, Guerra S, Nieuwenhuijsen MJ. Respiratory and inflammatory responses to short-term exposure to traffic-related air pollution with and without moderate physical activity. *Occup Environ Med* 2015; 72: 284–293.

23. Laeremans M, Dons E, Avila-Palencia I, Carrasco-Turigas G, Orjuela JP, Anaya E, Cole-Hunter T, de Nazelle A, Nieuwenhuijsen M, Standaert A, Van Poppel M, De Boever P, Int Panis L. Short-term effects of physical activity, air pollution and their interaction on the cardiovascular and respiratory system. *Environ Int* 2018; 117: 82–90.

24. Stergiopoulou A, Katavoutas G, Samoli E, Dimakopoulou K, Papageorgiou I, Karagianni P, Flocas H, Katsouyanni K. Assessing the associations of daily respiratory symptoms and lung function in schoolchildren using an Air Quality Index for ozone: Results from the RESPOZE panel study in Athens, Greece. *Sci Total Environ* 2018; 633: 492–499.

25. Choi J-Y, Baumgartner J, Harnden S, Alexander BH, Town RJ, D'Souza G, Ramachandran G. Increased risk of respiratory illness associated with kerosene fuel use among women and children in urban Bangalore, India. *Occup Environ Med* 2015; 72: 114–122.

26. Lamichhane P, Sharma A, Mahal A. Impact of cleaner fuel use and improved stoves on acute respiratory infections: evidence from India. *Int Health* 2017; 9: 349–366.

27. Lewis JJ, Hollingsworth JW, Chartier RT, Cooper EM, Foster WM, Gomes GL, Kussin PS, MacInnis JJ, Padhi BK, Panigrahi P, Rodes CE, Ryde IT, Singha AK, Stapleton HM, Thornburg J, Young CJ, Meyer JN, Pattanayak SK. Biogas stoves reduce firewood use, household air pollution, and hospital visits in Odisha, India. *Environ Sci Technol* 2017; 51: 560–569.

28. Downward GS, van der Zwaag HP, Simons L, Meliefste K, Tefera Y, Carreon JR, Vermeulen R, Smit LAM. Occupational exposure to indoor air pollution among bakery workers in Ethiopia; a comparison of electric and biomass cookstoves. *Environ Pollut* 2018; 233: 690–697.

29. Yu K, Qiu G, Chan K-H, Lam K-BH, Kurmi OP, Bennett DA, Yu C, Pan A, Lv J, Guo Y, Bian Z, Yang L, Chen Y, Hu FB, Chen Z, Li L, Wu T. Association of solid fuel use with risk of cardiovascular and all-cause mortality in rural China. *JAMA* 2018; 319: 1351.

30. Mortimer K, Ndamala CB, Naunje AW, Malava J, Katundu C, Weston W, Havens D, Pope D, Bruce NG, Nyirenda M, Wang D, Crampin A, Grigg J, Balmes J, Gordon SB. A cleaner burning biomass-fuelled cookstove intervention to prevent pneumonia in children under 5 years old in rural Malawi (the Cooking and Pneumonia Study): a cluster randomised controlled trial. *Lancet* 2017; 389: 167–175.

31. Noonan CW, Semmens EO, Smith P, Harrar SW, Montrose L, Weiler E, McNamara M, Ward TJ. Randomized trial of interventions to improve childhood asthma in homes with wood-burning stoves. *Environ Health Perspect* 2017; 125: 097010.

32. Guarnieri M, Diaz E, Pope D, Eisen EA, Mann J, Smith KR, Smith-Sivertsen T, Bruce NG, Balmes JR. Lung function in rural Guatemalan women before and after a chimney stove intervention to reduce wood smoke exposure. *Chest* 2015; 148: 1184–1192.

33. Heinzerling AP, Guarnieri MJ, Mann JK, Diaz JV, Thompson LM, Diaz A, Bruce NG, Smith KR, Balmes JR. Lung function in woodsmoke-exposed Guatemalan children following a chimney stove intervention. *Thorax* 2016; 71: 421–428.

34. Quansah R, Semple S, Ochieng CA, Juvekar S, Armah FA, Luginaah I, Emina J. Effectiveness of interventions to reduce household air pollution and/or improve health in homes using solid fuel in low-and-middle income countries: a systematic review and meta-analysis. *Environ Int* 2017; 103: 73–90.

35. Thakur M, Nuyts PAW, Boudewijns EA, Flores Kim J, Faber T, Babu GR, van Schayck OCP, Been JV. Impact of improved cookstoves on women's and child health in low and middle income countries: a systematic review and meta-analysis. *Thorax* 2018; 73: 1026–1040.

36. Das I, Pedit J, Handa S, Jagger P. Household air pollution (HAP), microenvironment and child health: Strategies for mitigating HAP exposure in urban Rwanda. *Environ Res Lett* 2018; 13.

37. Accinelli RA, Llanos O, López LM, Pino MI, Bravo YA, Salinas V, Lazo M, Noda JR, Sánchez-Sierra M, Zárate L, da Silva J, Gianella F, Kheirandish-Gozal L, Gozal D. Adherence to reduced-polluting biomass fuel stoves improves respiratory and sleep symptoms in children. *BMC Pediatr* 2014; 14: 12.

38. Castañeda JL, Kheirandish-Gozal L, Gozal D, Accinelli RA, The Pampa Cangallo Instituto de Investigaciones de la Altura Research Group. Effect of reductions in biomass fuel exposure on symptoms of sleep apnea in children living in the peruvian andes: a preliminary field study: biomass and snoring in children. *Pediatr Pulmonol* 2013; 48: 996–999.

39. Seow WJ, Hu W, Vermeulen R, Hosgood Iii HD, Downward GS, Chapman RS, He X, Bassig BA, Kim C, Wen C, Rothman N, Lan Q. Household air pollution and lung cancer in China: a review of studies in Xuanwei. *Chin J Cancer* 2014; 33: 471–475.

40. Kim C, Gao YT, Xiang YB, Barone-Adesi F, Zhang Y, Hosgood HD, Ma S, Shu XO, Ji BT, Chow WH, Seow WJ, Bassig B, Cai Q, Zheng W, Rothman N, Lan Q. Home kitchen ventilation, cooking fuels, and lung cancer risk in a prospective cohort of never smoking women in Shanghai, China. *Int J Cancer* 2015; 136: 632–638.

41. Jin ZY, Wu M, Han RQ, Zhang XF, Wang XS, Liu AM, Zhou JY, Lu QY, Kim CH, Mu L, Zhang ZF, Zhao JK. Household ventilation may reduce effects of indoor air pollutants for prevention of lung cancer: a case-control study in a Chinese population. *PLoS One* 2014; 9: e102685.

42. Mu L, Liu L, Niu R, Zhao B, Shi J, Li Y, Swanson M, Scheider W, Su J, Chang SC, Yu S, Zhang ZF. Indoor air pollution and risk of lung cancer among Chinese female non-smokers. *Cancer Causes Control* 2013; 24: 439–450.

43. Hu W, Downward GS, Reiss B, Xu J, Bassig BA, Hosgood HD, 3rd, Zhang L, Seow WJ, Wu G, Chapman RS, Tian L, Wei F, Vermeulen R, Lan Q. Personal and indoor PM2.5 exposure from burning solid fuels in vented and unvented stoves in a rural region of China with a high incidence of lung cancer. *Environ Sci Technol* 2014; 48: 8456–8464.

44. Zhou Y, Zou Y, Li X, Chen S, Zhao Z, He F, Zou W, Luo Q, Li W, Pan Y, Deng X, Wang X, Qiu R, Liu S, Zheng J, Zhong N, Ran P. Lung function and incidence of chronic obstructive pulmonary disease after improved cooking fuels and kitchen ventilation: a 9-year prospective cohort study. *PLoS Med* 2014; 11: e1001621.

45. Liu F, Zhao Y, Liu YQ, Liu Y, Sun J, Huang MM, Liu Y, Dong GH. Asthma and asthma related symptoms in 23,326 Chinese children in relation to indoor and outdoor environmental factors: the Seven Northeastern Cities (SNEC) Study. *Sci Total Environ* 2014; 497-498: 10–17.

46. Langbein J. Firewood, smoke and respiratory diseases in developing countries-the neglected role of outdoor cooking. *PLoS One* 2017; 12: e0178631.

47. Kile ML, Coker ES, Smit E, Sudakin D, Molitor J, Harding AK. A cross-sectional study of the association between ventilation of gas stoves and chronic respiratory illness in U.S. children enrolled in NHANESIII. *Environ Health* 2014; 13: 71.

48. Lajoie P, Aubin D, Gingras V, Daigneault P, Ducharme F, Gauvin D, Fugler D, Leclerc JM, Won D, Courteau M, Gingras S, Heroux ME, Yang W, Schleibinger H. The IVAIRE project--a randomized controlled study of the impact of ventilation on indoor air quality and the respiratory symptoms of asthmatic children in single family homes. *Indoor Air* 2015; 25: 582–597.

49. Salvi D, Limaye S, Muralidharan V, Londhe J, Madas S, Juvekar S, Biswal S, Salvi S. Indoor particulate matter < 2.5 μm in mean aerodynamic diameter and carbon monoxide levels during the burning of mosquito coils and their association with respiratory health. *Chest* 2016; 149: 459–466.

50. Chen R, Zhao A, Chen H, Zhao Z, Cai J, Wang C, Yang C, Li H, Xu X, Ha S, Li T, Kan H. Cardiopulmonary benefits of reducing indoor particles of outdoor origin. *J Am Coll Cardiol* 2015; 65: 2279–2287.

51. Cui X, Li F, Xiang J, Fang L, Chung MK, Day DB, Mo J, Weschler CJ, Gong J, He L, Zhu D, Lu C, Han H, Zhang Y, Zhang J. Cardiopulmonary effects of overnight indoor air filtration in healthy non-smoking adults: a double-blind randomized crossover study. *Environ Int* 2018; 114: 27–36.

52. Shao D, Du Y, Liu S, Brunekreef B, Meliefste K, Zhao Q, Chen J, Song X, Wang M, Wang J, Xu H, Wu R, Wang T, Feng B, Lung CS-C, Wang X, He B, Huang W. Cardiorespiratory responses of air filtration: a randomized crossover intervention trial in seniors living in Beijing. *Sci Total Environ* 2017; 603-604: 541–549.

53. Karottki DG, Spilak M, Frederiksen M, Gunnarsen L, Brauner EV, Kolarik B, Andersen ZJ, Sigsgaard T, Barregard L, Strandberg B, Sallsten G, Møller P, Loft S. An indoor air filtration study in homes of elderly: cardiovascular and respiratory effects of exposure to particulate matter. *Environ Health* 2013; 12: 116.

54. Peng RD, Butz AM, Hackstadt AJ, Williams DAL, Diette GB, Breysse PN, Matsui EC. Estimating the health benefit of reducing indoor air pollution in a randomized environmental intervention. *J R Stat Soc Ser A Stat Soc* 2015; 178: 425–443.

55. Hackstadt AJ, Matsui EC, Williams DAL, Diette GB, Breysse PN, Butz AM, Peng RD. Inference for environmental intervention studies using principal stratification. *Stat Med* 2014; 33: 4919–4933.

56. Jia-Ying L, Zhao C, Jia-Jun G, Zi-Jun G, Xiao L, Bao-Qing S. Efficacy of air purifier therapy in allergic rhiniti. *Asian Pac J Allergy Immunol* 2018; 36: 217–221.

57. Park H-K, Cheng K-C, Tetteh AO, Hildemann LM, Nadeau KC. Effectiveness of air purifier on health outcomes and indoor particles in homes of children with allergic diseases in Fresno, California: a pilot study. *J Asthma* 2017; 54: 341–346.

58. Weichenthal S, Mallach G, Kulka R, Black A, Wheeler A, You H, St-Jean M, Kwiatkowski R, Sharp D. A randomized double-blind crossover study of indoor air filtration and acute changes in cardiorespiratory health in a First Nations community. *Indoor Air* 2013; 23: 175–184.

59. Mirabelli MC, Golan R, Greenwald R, Raysoni AU, Holguin F, Kewada P, Winquist A, Flanders WD, Sarnat JA. Modification of traffic-related respiratory response by asthma control in a population of car commuters. *Epidemiology* 2015; 26: 546–555.

60. Hasunuma H, Yamazaki S, Tamura K, Hwang YH, Ono R, Amimoto Y, Askew DJ, Odajima H. Association between daily ambient air pollution and respiratory symptoms in children with asthma and healthy children in western Japan. *J Asthma* 2018; 55: 712–719.

61. Maikawa CL, Weichenthal S, Wheeler AJ, Dobbin NA, Smargiassi A, Evans G, Liu L, Goldberg MS, Pollitt KJG. Particulate oxidative burden as a predictor of exhaled nitric oxide in children with asthma. *Environ Health Perspect* 2016; 124: 1616–1622.

62. Evans KA, Halterman JS, Hopke PK, Fagnano M, Rich DQ. Increased ultrafine particles and carbon monoxide concentrations are associated with asthma exacerbation among urban children. *Environ Res* 2014; 129: 11–19.

63. Ierodiakonou D, Zanobetti A, Coull BA, Melly S, Postma DS, Boezen HM, Vonk JM, Williams PV, Shapiro GG, McKone EF, Hallstrand TS, Koenig JQ, Schildcrout JS, Lumley T, Fuhlbrigge AN, Koutrakis P, Schwartz J, Weiss ST, Gold DR. Ambient air pollution, lung function, and airway responsiveness in asthmatic children. *J Allergy Clin Immunol* 2016; 137: 390–399.

64. Barchitta M, Maugeri A, Quattrocchi A, Barone G, Mazzoleni P, Catalfo A, De Guidi G, Iemmolo MG, Crimi N, Agodi A. Mediterranean diet and particulate matter exposure are associated with LINE-1 methylation: results from a cross-sectional study in women. *Frontiers in Genetics* 2018; 9: 514.

65. Steinemann N, Grize L, Pons M, Rothe T, Stolz D, Turk A, Schindler C, Brombach C, Probst-Hensch N. Associations between Dietary Patterns and Post-Bronchodilation Lung Function in the SAPALDIA Cohort. *Respiration* 2018; 95: 454–463.

66. Egner PA, Chen JG, Zarth AT, Ng DK, Wang JB, Kensler KH, Jacobson LP, Munoz A, Johnson JL, Groopman JD, Fahey JW, Talalay P, Zhu J, Chen TY, Qian GS, Carmella SG, Hecht SS, Kensler TW. Rapid and sustainable detoxication of airborne pollutants by broccoli sprout beverage: results of a randomized clinical trial in China. *Cancer Prev Res* 2014; 7: 813–823.

67. Heber D, Li Z, Garcia-Lloret M, Wong AM, Lee TY, Thames G, Krak M, Zhang Y, Nel A. Sulforaphane-rich broccoli sprout extract attenuates nasal allergic response to diesel exhaust particles. *Food Funct* 2014; 5: 35–41.

68. Hansell AL, Bakolis I, Cowie CT, Belousova EG, Ng K, Weber-Chrysochoou C, Britton WJ, Leeder SR, Tovey ER, Webb KL, Toelle BG, Marks GB. Childhood fish oil supplementation modifies associations between traffic related air pollution and allergic sensitisation. *Environ Health* 2018; 17: 27.

69. Tong H. Dietary and pharmacological intervention to mitigate the cardiopulmonary effects of air pollution toxicity. *Biochim Biophys Acta* 2016; 1860: 2891–2898.

70. Carlsten C, MacNutt MJ, Zhang Z, Sava F, Pui MM. Anti-oxidant N-acetylcysteine diminishes diesel exhaust-induced increased airway responsiveness in person with airway hyper-reactivity. *Toxicol Sci* 2014; 139: 479–487.

AQI VALUE	Actions to protect one's health from $PM_{2.5}$ (World AQI, 2019)	Actions to protect one's health from ozone (EPA AQI, 2014)
GOOD [0–50]	None	None
Moderate [51–100*]	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion	Unusually sensitive people should consider reducing prolonged or heavy exertion
Unhealthy for sensitive groups [101–150]	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion	The following groups should reduce prolonged or heavy outdoor exertion: people with lung disease such as asthma, children and older adults, people who are active outdoors
Unhealthy [151–200]	Active children and adults, and people with respiratory disease, such as asthma, should avoid prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion	The following groups should avoid prolonged or heavy outdoor exertion: people with lung disease such as asthma, children and older adults, people who are active outdoors. Everyone else should limit prolonged outdoor exertion
Very unhealthy [201–300]	Active children and adults, and people with respiratory disease, such as asthma, should avoid all outdoor exertion; everyone else, especially children, should limit outdoor exertion	The following groups should avoid all outdoor exertion: people with lung disease such as asthma, children and older adults, people who are active outdoors. Everyone else should limit outdoor exertion
Hazardous [300+]	Everyone should avoid all outdoor exertion	

*For particles ≤2.5 μm in diameter: an AQI of 100 corresponds to 35 μg m^{-3} averaged over 24 hours). For particles ≤10 μm in diameter: an AQI of 100 corresponds to 150 μg m^{-3} averaged over 24 hours). An AQI of 100 for ozone corresponds to an ozone level of 0.075 parts per million (averaged over 8 hours).

SUPPLEMENTARY FIGURE 1 Air quality index and protection measures.
The AQI is an index for reporting daily air quality and is divided into six categories to help individuals understand when AP levels reach levels of health concern in their communities.

AP: air pollution; AQI: air quality index; EPA: Environmental Protection Agency; $PM_{2.5}$: particulate matter with an aerodynamic diameter <2.5 μm.