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**Impacts of air pollution across
the life course – evidence
highlight note**

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Impacts of air pollution across the life course – evidence highlight note

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2 Introduction

The sheer number of scientific studies addressing the impact of air pollution on health is overwhelming. Nearly 60,000 studies are available, with over half of these being published in the last ten years¹. These have led to the World Health Organisation (WHO) describing air pollution as a global health emergency⁽¹⁾.

The evidence that air pollution harms our health throughout our lives, from conception to old age, was summarised in the Royal College of Physicians (RCP) report *Every breath we take: the lifelong impact of air pollution*, in 2016⁽²⁾

Since this time the evidence has continued to accumulate. This new evidence summary builds on the RCP report by addressing the impacts of air pollution across the life course, reviewing key studies published in the interim period on the links between air pollution and ill health. The note is divided into sections focusing on different stages of life, including evidence regarding the impact of air pollution from pre-foetal development until early adulthood. It aims to summarise key evidence, drawing on recent authoritative academic reviews and research studies, with an emphasis on those carried out in the United Kingdom, London, or cities with similar air pollution climates.

3 Summary and conclusions

New perspectives

The short-term impacts of air pollution (worsening of symptoms, hospitalisations, and deaths) and long-term impacts (disease development, attributable premature deaths and years of lost healthy life) have been known, extensively studied and reviewed for decades.

However, over the last ten years there have been over 35,000 new studies on air pollution and health. These have strengthened previous understanding, led to the downward revisions of the World Health Organization (WHO) air quality guidelines⁽³⁾, and shown impacts on health outcomes that have not

¹ Pubmed search “(air pollution OR air quality) AND health” on 16th January 2023 found 35,734 studies between 2012 and the start of 2023 and a total of 57,850 since 1932.

been considered in previous health impact assessments. Table 1 lists adverse health outcomes from air pollution at different stages of life that are highlighted in this report.

Numerous studies across Europe, including several conducted in London, have shown direct impacts of contemporary air pollution in our city. These include evidence that air pollution exposure is having impacts during pregnancy and affecting birth outcomes, that school children are experiencing slower lung-development, worsening of asthma symptoms, and poorer mental health, and that Londoners are suffering more disease in later life and dying earlier because of the air they breathe.

While headline figures on the health impact of air pollution focus on the equivalent number of premature deaths, the wider impacts are hiding in plain sight in the contribution of air pollution to the burden of chronic diseases. These affect our quality of life and have a large cost to society through additional health and social care costs, as well our ability to learn, work and contribute to society.

Perhaps, the most important new finding is evidence related to both the impact of air pollution on brain health, including mental health and dementia, and early life impacts that could lead to future health burdens within the population. Both represent significant, but currently unquantified costs to society and the economy.

Confidence in these health impacts stems from the triangulation of information from many studies: epidemiology, which looks at pattern of association, toxicology and mechanistic studies that address causal mechanisms, including human experimental studies. This report draws heavily on findings from expert panels including those convened by the World Health Organization, the UK Committee on the Medical Effects of Air Pollution, the Royal College of Physicians, the Health Effects Institute, and the International Agency for Research on Cancer. We also highlight research carried out in London and the wider UK to illustrate the evidence emerging in our own towns and cities.

Table 1 Summary of the health outcomes from air pollution that are highlighted in this report.

Life stage	Heath impact
Pregnancy and birth outcomes	Foetal development Low birth weight Gestational age and pre-term births Miscarriage Sperm count and mobility
The developing child: from birth, through adolescence	Lung growth Asthma Blood pressure Cognitive abilities Inattention and hyperactivity Mental health and illness
Adulthood	Early death Cardiac health Stroke Brain and mental health Respiratory health

	Cancer Multiple chronic illnesses
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Policy implications

Each breath we take contains a complex mixture of pollutants. It can therefore be difficult to separate out the individual impacts of these multiple components. However, it is clear that a substantial part of the health burden from air pollution comes from small respirable particles, most especially those referred to as PM_{2.5}, and also from the gas, nitrogen dioxide.

Actions and policies to reduce the concentrations of air pollution are often framed in terms of meeting legal limit values to minimise the harm to human health. These limits should not be perceived, or presented as ‘safe’, non-toxic thresholds. Abundant evidence suggests significant impacts below these concentrations, and for some pollutants, such as PM_{2.5} there is no evidence to identify a threshold where exposure does no harm. **The latest evidence, reflected by the new WHO guideline concentrations for PM_{2.5} and nitrogen dioxide, suggest that current levels of air pollution in London will affect all citizens, including those living in the least polluted suburbs, and especially those with pre-existing vulnerabilities.**

Reports from the 1970’s onwards have emphasised the importance of providing the public with better air pollution information, but this information needs to be actionable, focused on reducing individual exposures, and should not be a diversion from measures to reduce pollution emissions. Controlling emissions will provide the greatest benefit to all, but actions are required at all levels of government and health care to also educate about the risks of air pollution and provide advice to reduce exposures in the shorter term, through actions such as behaviour change.

Evidence on the benefits of air pollution reduction focus on reducing ambient air pollution exposure over wide areas and large populations. Logically, exposure reduction on the smaller neighbourhood scale, around our schools for instance, or in our everyday lives should also lead to health improvement.

The focus on achieving current limits can lead to actions on the most polluted places but provides little incentive to drive down air pollution in other locations. It can also be a barrier to progress when limits are set according to their achievability in the most polluted places.

For PM_{2.5}, European and UK legislation includes targets to reduce the average exposure across the whole population, but there is also an urgent need to incorporate population vulnerability in air pollution priorities. **Policies should be aimed at reducing the accumulating harm from air pollution and the health degradation, in addition to protecting people who have become vulnerable to current pollution concentrations.**

4 Definitions

Terms	Definition
Black Carbon and Elemental Carbon	Black carbon is a very fine particulate air pollution (PM _{2.5}), commonly known as soot. It comes from the burning of diesel, gas and coal, as well as biomass (wood).
Nitrogen oxides - NO ₂ and NO _x	Nitrogen oxides (NO _x) are a group of pollutant that includes nitrogen dioxide, a known toxic gas. Nitrogen dioxide (NO ₂) breaches legal limits alongside many of London roads.
Ozone (O ₃)	Near the ground, ozone is a component of air pollution that occurs when NO _x reacts with certain chemical compounds that are released into the air due to everyday industrial activities and many of the personal care and solvent products that we use in our homes. As its formation is driven by solar ultraviolet radiation, concentrations tend to be higher during the summer months.
PM _{2.5} and PM ₁₀	Particulate matter (PM) refers to very small air pollution particles which can pass beyond our nose and throat and enter into respiratory system. PM _{2.5} particles are smaller than PM ₁₀ .
Sulphur dioxide (SO ₂)	A gas from the burning of fuels that contain sulphur, typically from coal and petrochemicals.

5 Pregnancy & birth outcomes

New evidence indicates that air pollution can impact our immediate and long-term health even before we are born⁽⁴⁾. As a foetus undergoes rapid growth and development throughout pregnancy, it is vulnerable to environmental factors that can impact its transformation. There is evidence that certain inhaled toxicants can enter the blood, cross the placental barrier to interact with the developing foetus⁽⁵⁾. A pregnant woman's exposure to air pollution is therefore, in essence, also the exposure experienced by the foetus, a notion supported by recent studies identifying links between air pollution and gestational age (the age in weeks when a baby is born), birth weight, miscarriages and stillbirth⁽²⁾. The WHO⁽⁶⁾ estimates that every year, more than 20 million babies are born with low birth weight, and another 15 million babies are born prematurely, before 37 weeks gestational age, a known contributor to infant mortality⁽⁷⁾. This section outlines the latest research attempting to understand how much air pollution may contribute to adverse pregnancy and birth outcomes.

Foetal development: air pollution pathways to the foetus

Air pollution particles are inhaled through the mother and can cause adverse effects on foetal development via two different pathways: either the particles themselves, and their associated chemicals can enter the blood stream to impact directly on the placenta and foetus, or indirectly via pollution induced inflammation impacting on the maternal circulation. In the mother, air pollution exposures have been associated with a multitude of adverse effects, including inflammation, oxidative stress and high blood pressure (pre-eclampsia)⁽⁸⁾. Air pollution has been associated with altered blood flow between the umbilical cord and placenta, lowering oxygen levels, and this has been proposed as a potential mechanism for the slowed or delayed foetal growth⁽⁹⁾.

Birth Outcome: Low Birth Weights

Low birth weight (LBW) and preterm birth (PTB) are established risk factors for early life mortality and lifetime morbidity⁽¹⁰⁾. Numerous studies have shown the impact of PM_{2.5} air pollution on a range of perinatal² health outcomes. A study by Smith and colleagues published in 2017⁽¹¹⁾, observed that modelled PM_{2.5} exposures (at home address) greater than 13.8 µg m⁻³ during pregnancy was directly associated with slower foetal growth rates, contributing to approximately 3 percent of infants born in London with LBW. The impact of PM_{2.5} on foetal development was subsequently reinforced by a review of 124 global studies, which estimated that PM_{2.5} air pollution was associated with a 7.5-13 gram reduction in birth weight in UK-born babies⁽⁹⁾. Within London a study⁽¹¹⁾ has examined 540,365 births in the capital and found that long-term exposure to nitrogen dioxide (NO₂) and PM_{2.5} were all associated with increased risk of low birth weights. There was also evidence that PM_{2.5} and PM₁₀ exposures during the third trimester were associated with adverse foetal growth rates.

Birth Outcome: Gestational Age & Preterm Births

A global study conducted by Malley *et al.*, (2017)⁽¹²⁾ examined the total number of preterm births associated with maternal exposure to PM_{2.5}. They found that 18 percent of all pre-term births worldwide were associated with an annual average concentration of PM_{2.5} exposure higher than 10 µg m⁻³. The same study estimated that in 2010, the percentage of total preterm births in the UK associated with PM_{2.5} (of more than 4.3 µg m⁻³) as between 5-10 percent. According to Ghosh *et al.*, (2021)⁽⁹⁾, the average reduction in gestational age attributable to PM_{2.5} was between 0.4 and 0.7 weeks (approximately 3 – 5 days). Smith *et al.*, (2017)⁽¹¹⁾ also identified that exposure to ozone (O₃) was associated with a higher risk of pre-term birth.

It has been estimated that 2.8 million low-weight births and 5.9 million pre-term births could be avoided globally if PM_{2.5} exposure during pregnancy was maintained at the theoretical minimum risk exposure levels from 2.4 to 5.9 µg m⁻³⁽⁹⁾; a concentration range close to the WHO Guideline of 5 µg m⁻³ but well below that currently measured in London, which were between 10 and 14 µg m⁻³ in 2019⁽¹³⁾.

² The time period that includes pregnancy and the year following birth.

Miscarriage

While studies examining the relationship between air pollution with miscarriages and stillbirth in the UK are still limited, the paper by Smith *et al.*, (2017) ⁽¹¹⁾ identified a small increased risk of stillbirth associated with non-exhaust PM_{2.5} and ozone during the first two trimesters of pregnancy. While more research is needed to understand the extent of this risk, mitigation, and regulation to better manage poor air quality could reduce these risks during pregnancy.

Sperm health

Concern about the impact of air pollution on reproductive health is not restricted to the mother, with recent studies and reviews highlighting adverse associations with a range of sperm parameters. A review and meta-analysis with over 4,562 males found that exposure to higher air pollution was associated with significant decreases in semen volume, concentration of sperm, motility, and normal morphology. This included studies carried out around the globe including in China, Taiwan, Italy, Turkey, the Czech Republic and USA. One weakness in the review is the different pollutants considered in each study. Although most focused on airborne particles, others encompassed many pollutants including carbon monoxide (CO), polycyclic aromatic hydrocarbons and SO₂, with studies spanning 1993 to 2008 ^(14, 15). A more recent study in China looked at the sperm quality of over 30,000 men and found an association between PM_{2.5} pollution and sperm motility. Pollution exposures were greater than those in the UK with a mean of around 46 µg m⁻³⁽¹⁶⁾.

6 The developing child: from birth through adolescence

Childhood and adolescence are periods of rapid growth during which organ systems are particularly susceptible to developmental impairment and damage. These earlier life impacts are increasingly understood to have lifelong consequences on an individual's vulnerability to chronic disease as they age.

Evidence on the air pollution breathed by London school children point to opportunities for interventions to reduce their exposure. In 2019, 258 pupils in London were given a rucksack capable of monitoring air pollution to wear for a week. In addition to air pollution breathed at home and in their neighbourhoods, air pollution on the journey to and from school was a major source of the children's exposure. On average, particle pollution (PM_{2.5}) on their journey was over 50 percent greater than that in the school environment. The children who travelled by car breathed more air pollution than those who walked along quiet roads, with the greatest concentrations being around 20 µg m⁻³. Walking along main roads led to the greatest exposure, being 33 percent greater than the exposure for those who walked along quieter roads⁽¹⁷⁾. As well as a focus on children's home neighbourhoods, improving air pollution around schools, reducing traffic and encouraging walking along less busy roads could therefore help to reduce children's air pollution exposure.

Other initiatives include studies on school streets. A study of 16 school streets in London showed that nitrogen dioxide, one of the major pollutants from traffic, was reduced by 23 percent when traffic was restricted on the school street and the number of children walking or cycling to school increased by 18 percent⁽¹⁸⁾. With careful design, this can lead to traffic reductions over a wider area^(19, 20).

Lung growth

There is now substantial evidence that air pollution exposure affects children's lung growth. This first emerged through research in Southern California in the 1990s⁽²¹⁾.

Reduced lung volumes have been found in primary school aged children growing up in inner-city London. This finding arose from a study conducted between 2009 and 2014, over the period when the original Low Emission Zone was being implemented in London. Researchers tested the lung function of over 2,000 children (aged 8-9) and found that on average a child had lost around 5 percent of their expected lung volume because of the air pollution that they breathed. This effect was most clearly linked with exposure to NO₂, which is often used as a tracer for the diesel exhaust emissions. Although a change of this magnitude is unlikely to be clinically significant in the healthy population, the more important issue is whether this change leads to an inability to attain maximal lung development by adulthood, which if not achieved has potential impacts on long-term health⁽²²⁾.

This observation in London school children was consistent with the earlier findings of the European Study of Cohorts for Air Pollution Effects (ESCAPE) study. This study analysed data from nearly 6,000 children from five European birth cohorts and showed that poor air quality was associated with reduced lung function in pre-adolescent children (aged 6–8)⁽²³⁾.

It is important to note that the air pollution concentrations, particularly NO₂ experienced by the children in the London primary school study were significantly greater than those observed in Californian and ESCAPE studies reflecting the air pollution challenges in London prior to the introduction of the Ultra-Low Emission Zone (ULEZ).

Adverse health effects have also been seen in relatively low pollution environments, far below those experienced in London. In Stockholm County, Sweden, lung growth in a cohort of adolescents (aged 16 years) has been related to early life air pollution exposures⁽²⁴⁾. These adolescents lived in neighbourhoods with median NO_x and PM₁₀ and of 10 and 4.4 µg m⁻³. This is around half the lowest NO_x concentrations measured in London in 2019 and a third of the lowest PM₁₀.

In further support of the dangers of air pollutants there is evidence that policies to reduce air pollution can deliver measurable health benefits. Analysis of consecutive cohorts in the Californian Children's Health Study⁽²⁵⁾, found fewer children with clinically small lungs as air quality improved between 1994 and 2011. This has been supported by a recent (February 2023) study on the Swedish cohort mentioned above that found improvements in air pollution (PM_{2.5}, BC and NO_x) was associated with improvements in lung growth, even at the relatively low air pollution experienced in Stockholm⁽²⁶⁾, again at concentrations below those currently experienced throughout London.

Asthma

It has long been recognised by clinicians that asthmatic patients find breathing more difficult when exposed to polluted air, a contention supported by an extensive literature demonstrating a worsening of symptoms, increased use of reliever medications, hospital admissions and deaths during and after periods of elevated air pollution^(27, 28). Exacerbations requiring emergency health-care were considered in a review of 21 studies in 2016⁽²⁹⁾. Significant associations were found with NO₂, SO₂ and PM_{2.5}. These studies examining associations between air pollution and a range of asthma endpoints, are supported by experimental evidence, including human exposure studies that have shown that air pollution, and particularly that derived from traffic exhaust, causes inflammation in the lung, increases airway hypersensitivity and acts to sensitize the airway to subsequent allergen challenge^(27, 28).

A review of 21 epidemiological studies from 2000 to 2016, Khreis *et al.*, (2017)⁽³⁰⁾ found significant associations between development of asthma in children and exposure to traffic related air pollution, specifically (black carbon, nitrogen dioxide [NO₂]), PM_{2.5} and PM₁₀. More recently, in 2022, the US Health Effects Institute reviewed 118 studies on children and traffic pollution and found moderate to high confidence in the association with air pollution exposures and asthma onset and lower respiratory infections.^(31, 32)

The developing cardiovascular system

Currently there is limited research concerning long-term impacts of air pollution on the developing cardiovascular system.

US and Dutch studies have found positive associations between atherosclerosis (narrowing of arteries) in adolescents and air pollution. The US study focused on pollutants from traffic including NO_x and PM_{2.5} while the Dutch study focused on particle pollution, including PM_{2.5}^(33, 34).

A 2022 review identified 24 studies examining air pollutants and blood pressure in children and adolescents: eleven in China, one in Pakistan, three in the US and nine in Europe. Study designs and findings varied. One London-based study then addressed this question by examining how blood pressure changes over the transition from childhood to adolescence were influenced by long-term exposures to NO₂ and PM_{2.5}. This study looked at 3,824 London youths, aged 11-16 recruited into the longitudinal, ethnically diverse DASH (Determinants of Adolescent Social well-being and Health) cohort. The authors found a positive association between the two pollutants and systolic blood pressure. While increases in NO₂ were linked to a decrease in systolic BP, increases in PM_{2.5} led to increases in systolic BP. While this study was consistent with previous investigations, more information is needed to understand the implications of air pollution on blood pressure and cardiovascular function⁽³⁵⁾.

Cognitive abilities, inattention and hyperactivity

If you talked to parents on the 1970s and 1980s their main concern was around brain damage to their children from lead. This was used as an additive to petrol until it was finally banned in 1999^(36, 37). Over the years that followed air pollution research focused elsewhere and has only recently returned to the linkages between cognition, inattention and hyperactivity and air pollution in children.

More recently traffic-related air pollution exposure has been associated with adverse effects on cognitive, behaviour and psychomotor development in children. Traffic-related air pollution has the potential to negatively impact the development of different parts of the brain. Based in Barcelona, the BREATHE project looked at levels of air pollutants in the school environment and how they may impact brain development in 263 children and found that smaller sized brains were positively associated with greater PM_{2.5} exposure. The researchers conducted processing and operation tests with the participants and found that older children displayed signs of slower brain development, indicating that increased exposure over time negatively impacts brain maturation⁽³⁸⁾.

A study of 2,687 school children from 39 schools in Barcelona/Catalonia, Spain found that children exposed to higher daily levels of NO₂ and the elemental carbon (EC) within PM_{2.5} had slower response times to computerised tests⁽³⁹⁾. Overall, the study found that increased NO₂ levels resulted in slower reaction times and a higher rate of unanswered questions from participants, with similar findings for

both daily and long-term exposure rates – meaning traffic related pollution has the potential to impact attention processes daily, irrelevant of the indoor air pollution within the classrooms. Long-term exposure to indoor NO₂ was also found to negatively impact attention capabilities as well as working memory. This study adds to the evidence that air pollution may have potential harmful effects on neurodevelopment⁽⁴⁰⁾. A previous study found that behavioural issues such as hyperactivity and inattention, as well as conduct problems and emotional symptoms, increased in children aged 7 to 11 with increased levels of exposure to traffic-related air pollution⁽⁴¹⁾.

Mental Health & Illness

In England, as of 2017, 1 in 8 youths, aged 5 to 19 years have been diagnosed with mental health problems, which can have significant negative impacts on daily life, as well as long-term implications⁽⁴²⁾. As children and adolescents are still developing, air pollution can pose a great risk to their physical and mental health. A long-term study examined the relationship between air pollution exposures and mental health/behaviour in 284 London-based same-sex twins with an average age of 12⁽⁴³⁾. After adjusting for external factors such as smoking and socioeconomic status, the study found that adolescents with higher yearly air pollution exposure levels at age 12 displayed a significantly greater risk of either a major-depressive or conduct-disorder diagnoses or at age 18. A 2021 study using some of the same participants, explored the connection between air pollution exposure at age 10 and major depressive disorder diagnoses at age 18. This study found those exposed at age 10 to higher levels of NO_x and PM_{2.5} were also at higher risk for a positive diagnosis⁽⁴⁴⁾. Another 2021 study found that increased NO_x exposure was linked to increased rates of mental illness among participants⁽⁴⁵⁾.

7 Adulthood

Early death

In 1993, the publication of the US “Six Cities Study”⁽⁴⁶⁾ changed our understanding of air pollution. Put simply, after allowing for socioeconomic factors, such as smoking, work history and poverty, it found that those adults living in more polluted places lived shorter lives and that the degree of life-shortening was associated with the PM_{2.5} in their city. Results from this study and the similar ones that followed still have great relevance today. For instance, they enable us to estimate the health burden of air pollution in London. The latest estimate is a 3,600 to 4,100 deaths attributable to human-made PM_{2.5} and NO₂ in London in 2019⁽⁴⁷⁾.

Cardiac health

Cardiac deaths and hospitalisations have been long associated with air pollution exposures. This association was found by Dockery *et al.*, (1993)⁽⁴⁶⁾ – the “Six Cities Study” - and in many studies since. These include the European-wide ESCAPE project which found that acute coronary events were associated with air pollution breathed over a ten-year period, with effects seen at airborne particle (PM_{2.5}) concentrations less than current European limit of 25 µg m⁻³ and also below 15 µg m⁻³, similar to the concentrations that prevail in London⁽⁴⁸⁾. In 2016 the Royal College of Physicians⁽²⁾ concluded that there was strong evidence for the effects of short and long-term exposure to air pollution on cardiovascular disease in adults, but it was unclear if air pollution breathed in early life affected the

development of cardiovascular disease later in life. Just last year, a systematic review of studies on health and long-term exposure to traffic related pollution was carried out by the US Health Effects Institute^(31, 32). This covered 352 studies over 40 years of research. High confidence was attached to the association with deaths from circulatory and ischemic heart disease and moderate confidence in the association with ischemic heart disease.

Stroke

There is increasingly compelling evidence that air pollution exposure increases stroke risk. In the short-term, exposure to air pollution is a risk factor for having a stroke and for outcomes in terms of hospitalisation and mortality. The majority of studies show that longer term exposure to air pollution may also increase the risk of stroke. These include analysis that bring together the results of over 20 other studies covering over 10 million people⁽⁴⁹⁾.

The European ESCAPE study considered stroke in nearly 100,000 people over a ten-year period and found some evidence of an association between long term exposure to PM_{2.5} and stroke, especially amongst people over 60 years old. This was observed at concentrations below European limits of this pollutant and also below 15 µg m⁻³, similar to the concentrations that prevail in London⁽⁵⁰⁾.

Brain and mental health

Increasing confidence on the associations between air pollution, mental health, cognitive decline, and dementia is one of the most significant recent developments in our knowledge of the way that air pollution may be affecting our health and is an area of active research.

A new review, Thompson *et al.*, (2023)⁽⁵¹⁾ identified 86 studies that considered air pollution and cognition concluding that there was much evidence that was supportive of associations between environmental air pollution and cognition in humans, but not for all pollutants and all cognitive outcomes. Important differences in which aspects of cognition (IQ, cognition, verbal fluency etc) were being assessed hampered their comparison and there was an important lack of studies in young adults. However, there was moderate certainty around detrimental associations between some pollutants (mainly PM_{2.5}, NO₂ and NO_x) with some aspects of cognition, especially in children and adults over 40 years old.

In London, a study of 1,698 adults (mean ages 40 for men and 43 for woman) living in Lambeth and Southwark in 2008 to 2013 revealed results consistent with urban air pollution having a significant impact on poor mental health, which could not be explained by other indices of urbanicity or socioeconomic deprivation. Comparing those in the least and greatest concentrations of PM_{2.5}, NO_x and NO₂ there were robust associations with 18–39 percent increased odds of common mental disorders, 19–30 percent increased odds of poor physical symptoms and 33 percent of psychotic experiences, which was only found with PM₁₀ exposures⁽⁵²⁾.

In 2016 the Royal College of Physicians⁽²⁾ noted emerging evidence that air pollution accelerates cognitive decline with aging and increases the risk of dementia. In 2022, the Committee on the Medical Effects of Air Pollution reviewed 69 studies in human populations as well as experimental studies, concluding that evidence suggested an association between air pollution exposure, the risk of developing dementia and the acceleration of cognitive decline. This was most likely to be from exposure to particle pollution⁽⁵³⁾. Castellani *et al.*, (2022)⁽⁵⁴⁾ responded by setting out a policy agenda

that covers research to fill knowledge gaps as well as the need to build awareness amongst the public and third sector, national and local government, and agencies. They concluded that actions to reduce exposure must be seen in a wider context of social determinants that can be changed, including poverty, transportation, health inequalities and urban planning.

Respiratory health

The linkage of air pollution and respiratory impacts were firmly established by the tragedy of the 1952 smog, where bronchitis was overwhelmingly the greatest cause of death^(36, 55). In their first air pollution report in 1970, the Royal College of Physicians⁽⁵⁶⁾ concluded that there was “no doubt” that the high pollution events in UK cities led to immediate harm and that evidence pointed to a causal relation between air pollution and deaths from bronchitis. However, at that time the impacts of long-term exposures were hard to distinguish from other environmental factors.

In 2022 the US Health Effects Institute⁽³¹⁾ placed moderate to high confidence in the association of long-term exposure to traffic pollution and the onset of asthma in adults.

A review of 22 studies in 12 (mostly high income) countries covering 267,413 visits to emergency departments, emergency calls, or hospitalizations due to asthma and found associations with air pollutants including NO₂, PM_{2.5} and O₃. In general, adult asthmatics were less affected by air pollution compared with children⁽²⁹⁾.

It is also clear that the elderly (older than 65 in most studies) are more susceptible to air pollution than other adults. There are well-documented associations between short-term exposure to air pollution and respiratory morbidity in the elderly. Air pollution exposures are also associated significant increases in hospitalizations, emergency department or home medical visits for respiratory causes, mainly Chronic Obstructive Pulmonary Disease (COPD – an umbrella term for bronchitis and emphysema), asthma, and pneumonia. A 2014 review concluded that the role of air pollution in the development of COPD was uncertain⁽⁵⁷⁾. A later 2015 review focusing on the elderly (those 65 or over) found that chronic exposure to elevated levels of air pollution was related to the risk of having COPD and asthma. Growing evidence also suggests adverse effects on lung function in the elderly⁽⁵⁸⁾.

Two studies have looked at elderly Londoners who suffer from chronic obstructive pulmonary disease. Pfeiffer *et al.*, (2019)⁽⁵⁹⁾ found that increased NO_x (a gaseous pollutant often used as a tracer for traffic pollution) led to more COPD exacerbations and slower recovery. Evangelopoulos *et al.*, (2021)⁽⁶⁰⁾ supplied wearable pollution sensors to over 100 COPD sufferers and found the increases in gaseous air pollution was associated with more frequent exacerbations.

Analysis by Imperial College London⁽⁶¹⁾ estimated that London’s poor air quality led to over 1,700 hospital admissions for asthma and serious lung conditions between 2017 - 2019. Within these, exacerbation of asthma by air pollution led to around 700 hospital admissions in children from 2017 – 2019. This was 7% of all asthma admissions in children in the capital. The numbers for adults were smaller (around 200 admissions from 2017 - 2019). Chronic obstructive pulmonary disease (COPD) is more common in the elderly and is difficult to distinguish from asthma. Estimates for the elderly therefore combined asthma and COPD. The study estimated that exacerbation of asthma and COPD by air pollution lead to around 900 hospital admissions from 2017-2019 in the elderly in London. However, improvements in air pollution were estimated to have reduced asthma admissions from air

pollution by 30% in children since 2016. The equivalent reductions for asthma in adults and COPD/asthma in the elderly were 27% and 26%, respectively.

Cancer

The Six Cities Study⁽⁴⁶⁾ was amongst the first to show an association between long term exposure to air pollution and lung cancer in both smokers and non-smokers. A 2009 report by the UK Committee on the Medical Effects of Air Pollution (COMEAP) recognised the relationship between air pollution exposure and lung cancer and included recommendations for quantifying the impact⁽⁶²⁾. In 2012 the International Agency for Cancer Research (IARC) classified diesel exhaust as carcinogenic to humans (group 1). This was followed in 2013 by similar classification for outdoor air pollution, specifically for lung cancer. They also noted an association with bladder cancer^(63, 64). Airborne particulate matter was looked at separately, and also classified as a class 1 carcinogen. This classification was shortly followed by European study, using data from nine countries, including the UK, that showed associations between particle pollution, both PM_{2.5} and PM₁₀ and lung cancer⁽⁶⁵⁾. In an important breakthrough in 2022, scientists at the Francis Crick Institute⁽⁶⁶⁾ in London announced the results of research that may explain the way in which particle pollution could cause lung cancer in people that have never smoked, by inducing an inflammatory environment in the lung that promotes the growth of cells carrying cancer-causing mutations⁽⁶⁷⁾.

Chronic illness

In addition to shortening lives, a new UK study, the largest of its kind to date, has found that people living in polluted areas were more likely to be living with more than one long-term illness⁽⁶⁸⁾. These long-term problems affect people's lives, and place significant burdens on our economy and health services. The researchers looked at more than 360,000 people aged between 40 and 69 who had health data in UK Biobank. Forty three percent had multiple long-term illness. There were clear associations between air pollution (NO₂ and PM_{2.5}) and the chances of multiple neurological, respiratory, cardiovascular ill-health as well as associations with common mental health conditions such as depression and anxiety, even after allowing for differences in income. Associations were seen between the amount of exposure to PM_{2.5} or NO₂ and the number of people with multiple long-term illness, adding to the plausibility of the air pollution associations. There was an extra 20 percent chance of multiple long-term illnesses for those living with PM_{2.5} particle pollution that is worse than the 2040 England target of 10 µg m⁻³. The study was, however, a snap-shot and was therefore not able to examine if air pollution caused these long-term illnesses, or led to a deterioration.

A study of 13 million Canadians found that short-term increases in air pollution increased the risk of emergency department visits for people with chronic illness including those with non-smoking related lung cancers, COPD and diabetes⁽⁶⁹⁾.

Evidence continues to accumulate indicating that air pollution is associated with an ever-wider range of health endpoints, many of which are likely to have significant and as yet unquantified costs to society and our health care systems. For example, recent work has associated long term air pollution exposures with an increased risk of osteoporosis⁽⁷⁰⁾.

8 Impacts that run through the life course

In their first report on air pollution and health in 1970, the RCP⁽⁵⁶⁾ suggested that the development of chronic illness later in life may stem from the damage caused by air pollution from childhood. However, it was recognised that assessing these connections between harm caused during one phase of life with impacts occurring many decades later was not possible at that time. Similarly, the RCP (2016)⁽²⁾ report highlighted the impacts of air pollution at different stages of our lives, but there were few studies on how exposure to air pollution at one point in our lives could impact on long term health. Such studies require individuals to be tracked over many decades and detailed information on exposure over this extended period.

Three newer UK studies however support the idea of impacts that run through the life course.

The first⁽⁷¹⁾ looked at children who experienced the London 1952 smog either *in utero* or during their first year of life. Compared with similarly aged children in other UK cities, the Londoners had a 20 percent greater chance of developing asthma in childhood. Although on the margins of statistical significance, there was a 10 percent increase in their rate of asthma as adults.

The second study⁽⁷²⁾ took at 1 percent sample of the 1970 English census and followed these individuals in the census that followed. The probability of death between each census was mainly associated with air pollution exposure in the previous decade, but smaller associations were found between air pollution exposures and mortality over a period of more than 30 years. This was the case for both cardiac and respiratory mortality.

The third study⁽⁷³⁾ considered the deaths of over 3.5 million people, aged over 35 between 1993 and 2012 in England and Wales. Associations were found with local domestic coal consumption in the 1950s and the risk of death in periods spanning up to 60 years, even having allowed for social class, education, crowding and unemployment in 1951, as well as contemporary social factors. Mortality risks included respiratory problems, including those like pneumonia acquired later in life, as well as cardiac problems. Risks of dying were greatest for those born during 1952 and 1953 suggesting that early life exposure to smog may present a life-long risk.

9 A note on association and causation

Epidemiological analysis of air pollution and health data are generally based on observations and not experiments. Statistical association, or apparent linkage, from these studies is not the same as causation.

Confidence that an association is causal requires the triangulation of information from many studies. Factors to be considered include the strength of the association, consistency across different types of study and populations, that exposure comes before effect, a dose response relationship (more air pollutant, more effect), biological plausibility, an absence of alternative plausible explanations and evidence that the reducing the exposure decreases the risk. To inform policy it is therefore important to draw together results from many studies through reviews and meta-analysis along with the work of expert panels who pull together evidence from many sources. Our report refers to expert panels including those convened by the World Health Organization, the UK Committee on the Medical Effects of Air Pollution (COMEAP), the Royal College of Physicians (RCP), the Health Effects Institute (HEI) and the International Agency for Research on Cancer (IARC).

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