Physical Activity and exposure to air pollution

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Contents

Executive summary

The aim of this project was to review the literature and find any evidence of health effects while performing physical activity (PA) in air pollution. This review was commissioned by the UK Health Security Agency (UKHSA) as part of work for the Air Quality Information Systems (AQIS) review.

We identified only a small number of studies (7 studies, six of which were in healthy individuals) that looked at the health effects of air pollution while engaged in physical activity (PA) compared to health effects of the same air pollution with no PA. Physical activity was found to have beneficial effects on pulmonary function and to attenuate a traffic-related air pollution increase in systolic blood pressure (generally PA alone increases blood pressure), compared to rest. Moreover, negative effects of particulate matter (PM) were found to be reduced with an increase in physical activity and that physically active individuals might have a lower risk of developing cardiovascular and metabolic diseases associated with PM exposure. One study showed high intensity PA was associated with increase in serum cytokines (TNF-a) which could indicate short-term inflammation.

To get a better understanding of the health effects of air pollution while exercising, we also included in this review a secondary group of studies (17 studies, 10 of which in healthy individuals) that didn't include any control groups (no non-PA groups). Most studies suggested that exposure to particulate matter levels during PA was associated with adverse health effects. In people with chronic diseases, it was determined that higher air pollution concentrations while doing PA could have larger negative effects on their health such as larger reduction in lung function, increase in pulse wave velocity etc.). However, it is unclear whether the health effects are due to a combination of the physical activity and the air pollution exposure or mainly due to the air pollution exposure since there is no control group.

We conclude that even in highly polluted environments, moderate PA has beneficial effects on pulmonary function in healthy individuals compared to no PA. Short-term exposure to high traffic pollution compared to lower exposure may offset some of the short-term beneficial cardiopulmonary effects of walking for healthy individuals and individuals with ischemic heart diseases and COPD. Greater reductions in lung function were observed in people with asthma when walking in high polluted roads compared to parks. The studies identified cannot be directly related to the DAQI as most of the studies only measure exposure during the PA time. For example, particulate DAQI levels are based on 24hr average which may not reflect the pollution levels during the specific PA exposure period. In some studies, negative health effects during PA were observed in air pollution levels as low as the current LOW – MID level DAQI bands (though as already mentioned, not directly comparable).

Moreover, an informal review of a few chamber studies outside the search criteria, suggests that there are adverse heath effects of air pollution while exercising, however most of the studies used very high air pollution levels. A comprehensive review is needed to better understand the effects and the conditions.

To add context to our review, we briefly reviewed literature on relationships between indoors and outdoors to enable readers to consider how outdoor air pollution concentrations might influence concentrations people are exposed to while exercising indoors. More understanding is needed on indoor/outdoor relationship, since the limited number of studies found on the subject suggest that exercising in indoor spaces could lead to higher exposure to air pollution depending on the room ventilation type and PM resuspension due to human activity.

All studies comparing PA to no PA during short-term air pollution exposure are focussed on healthy adults with no studies on children, people with pre-existing conditions or people doing manual labour. Moreover, most of the studies focused on particulate matter with very few studies focusing on NO_2 and O_3. Future research should prioritise randomized controlled trials (RCTs) in real world conditions, spanning a range of exposure levels, pollutant mixes, and physical activity levels, and include diverse groups of participants.

1 Introduction

Air pollution is a well-known risk factor for many health outcomes. It has been associated with worsening of existing heart and lung conditions, and increased risks for chronic obstructive pulmonary disease (COPD), asthma, heart attack, stroke, and premature mortality. In 2019, 40%, 26% and 20% of global deaths from COPD, stroke and ischemic heart diseases were attributed to air pollution, representing a huge health burden (Health Effects Institute, (2020)). In the UK, the annual mortality burden of current levels of air pollution has been estimated as an effect equivalent to 29,000 to 43,000 deaths (Mitsakou et al., (2022)).

Physical activity (PA) participation, in contrast, is one of the key lifestyle guidelines in prevention and rehabilitation of many chronic health conditions. Regular PA can significantly reduce the risks of certain types of cancers, diabetes, heart diseases, anxiety, depression and all-cause mortality, as well as improve biomarkers reflecting cardiovascular fitness, shortness of breath, oxygen consumption, and strength of respiratory muscles (Garcia et al., (2023)). PA is defined by World Health Organization (WHO) as any bodily movement produced by skeletal muscles that requires energy expenditure. The UK Chief Medical Officers' Guidelines recommend each adult to have weekly at least 150 minutes of moderate-intensity activity, or 75 minutes of vigorous-intensity activity, or an equivalent combination of both, to achieve health benefits (WHO, (2018); WHO, (2020)).

For both air pollution and physical activity engagement, the respective public health implications are well formulated; what is currently lacking to inform further policymaking is the combined health impacts of both. From a long-term perspective, each exposure might be expected to have opposite effects on health. However, most epidemiological evidence suggests that the long-term health benefits of regular physical activity still outweigh the risk of long-term exposure to air pollution, and that PA might mitigate the health risk of long-term air pollution exposure to some extent (Kim et al., (2020); Raza et al., (2021), Tainio et al., (2021)). In contrast, much less is known about the health impacts of short-term air pollution exposure while at the same time engaging in physical activity.

The relationship of simultaneous short-term air pollution exposure and physical activity is bi-directional. First, from a biological mechanistic point of view, exposure to air pollution will induce oxidative stress and inflammation while physical activity can initiate an anti-inflammatory response and better regulation of the metabolic system by improving glycolytic and oxidative substrate metabolism and insulin sensitivity (Hahad et al., (2021); Sinharay et a., (2018)). Second, deep rapid breathing with the increase of cardiopulmonary work and mouth breathing while exercising could cause increased air pollutant doses, and as such could increase health risks (DeFlorio et al., (2020); Hahad et al., (2021), Syed et al., (2022)). Third, days with high levels of air pollution can discourage people from undertaking physical activity outdoor, and hence the potential health benefits from PA may be completely lost (Tainio et al., (2021)). Researching the trade-off between short-term air pollution exposure and physical activity levels for the maximum health benefits is therefore key to bridging a gap in public

health policymaking. In this rapid review, we aim to investigate this important research question with regards to whether, and how, short-term exposure to air pollution may negate the health benefits of physical activity.

The Daily Air Quality Index (DAQI) in the UK provides information on current and forecast levels of air pollution and was based on recommendations made by the Committee on the Medical Effects of Air Pollutants (COMEAP) and was last comprehensively reviewed in 2011. The index is calculated based on concentrations of five pollutants: Nitrogen Dioxide (NO_2, 1-hr mean concentration); Sulphur Dioxide (SO_2, 15-min mean concentration); Ozone (O_3, 8-hr mean concentration); Particles < 2.5µm ($PM_{2.5}$, 24-hr mean concentration) and Particles < 10µm (PM_{10}, 24-hr mean concentration); and is communicated via a 10-point scale with four bands of low, moderate, high and very high and each banding is associated with accompanying health advice. The DAQI was developed to provide accessible information to those who may be particularly likely to experience adverse effects (at risk groups as adults and children with lung problems, adults with heart problems, and older people) during short-term episodes of elevated levels of air pollutants, as well as the general population. It is intended to enable individuals to make appropriate changes to their behaviour, in order to reduce the risk of experiencing adverse health effects. The advice includes reducing or avoiding strenuous activity outdoors, and also reminders regarding asthma medication.

2 Experimental Section

2.1 Criteria for Considering Studies for this Review

A modified systematic review approach was used to identify all relevant studies regarding the health impacts of PA in air pollution. The inclusion and exclusion criteria for the search are described below in Table 1.

Table 1: PECO eligibility criteria for paper identification

Components	Inclusion criteria	Exclusion criteria
Study type	Epidemiological studies including cohort studies, case-control studies, longitudinal studies, randomized controlled trials, observational studies; Experimental studies (including chamber studies); Mathematical modelling studies	Review studies for intervention, in-vitro, toxicological.
Population	Members of the general population; Population groups with potential for higher risks from air pollution: pregnant women, children, elderly people, people with chronic health conditions (e.g., cardiometabolic and respiratory), elite athletes and people doing high intensity exercise, manual labour workers (eg. construction site workers), lower socioeconomic status (deprivation), ethnic minority groups.	Exclude any Animal studies
Exposure	Environmental air pollution exposure from road, rail, aircraft, transport, industrial, etc. DAQI pollutants (Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide), and additionally black carbon and ultrafine particles	Studies where participants are exposed to indoor air pollution (a paragraph will be included in the discussion). Studies considering use of face masks to reduce exposure (paragraph in discussion)
Outcome	Risk of exacerbation of existing diseases, eg. CVD (incl. IHD, stroke, hypertension), metabolic disease (incl. DM), respiratory (COPD, asthma) Adverse impacts of short-term exposure to air pollution Disease markers: Lung function, Obesity, blood lipids/glucose levels, Cardiopulmonary fitness, inflammatory markers etc.	Health outcomes of unclear clinical health relevance; Educational attainment Quality of life – general wellbeing, Sleep Mental health disorders? Long-term exposure

2.2 Literature Search

Online databases OVID MEDLINE and EMBASE were searched using a search strategy developed in consultation with a librarian knowledge specialist in health sciences. The search was based around 3 categories; air pollution, physical activity and chronic disease (see full search strategy in Appendix A). 2063 studies identified through OVID MEDLINE and 6600

through EMBASE. Duplicates were removed from the results using https://sr-accelerator.com/#/deduplicator {accessed on 14.2.23}.

2.3 Screening

Due to the short amount of time available in the project and the large number of studies identified, the screening of titles and abstracts was shared between four reviewers. The "included" and "maybe" studies were then reviewed by a fifth reviewer. The three reviewers were MP, ET, YC, MB and the fourth reviewer was SC.

2.4 Data Extraction

The data extraction was shared between two reviewers with a common template. The template included: first author/publication year/title, study year, study design, study region, aim, study population, population characteristics (age and sex where available), exposure assessment (type), exposure range, PA FITT (Frequency, Intensity, Time, and Type), statistical analysis, confounders, investigated health outcomes, ascertainment of outcome, key findings and limitations/ uncertainties (the full extraction table can be found in Supplementary data (excel document)).

3 Results

A total of 24 studies were included in this report (see Fig. 1). The studies were separated into the primary aim of this review (Primary studies), which involves the comparison of the health effects of air pollution between PA and no PA, and the secondary aim, which involves studies investigating the health effects of exercising in air pollution (but with no formal control group (i.e., those not exercising)) (Secondary studies).

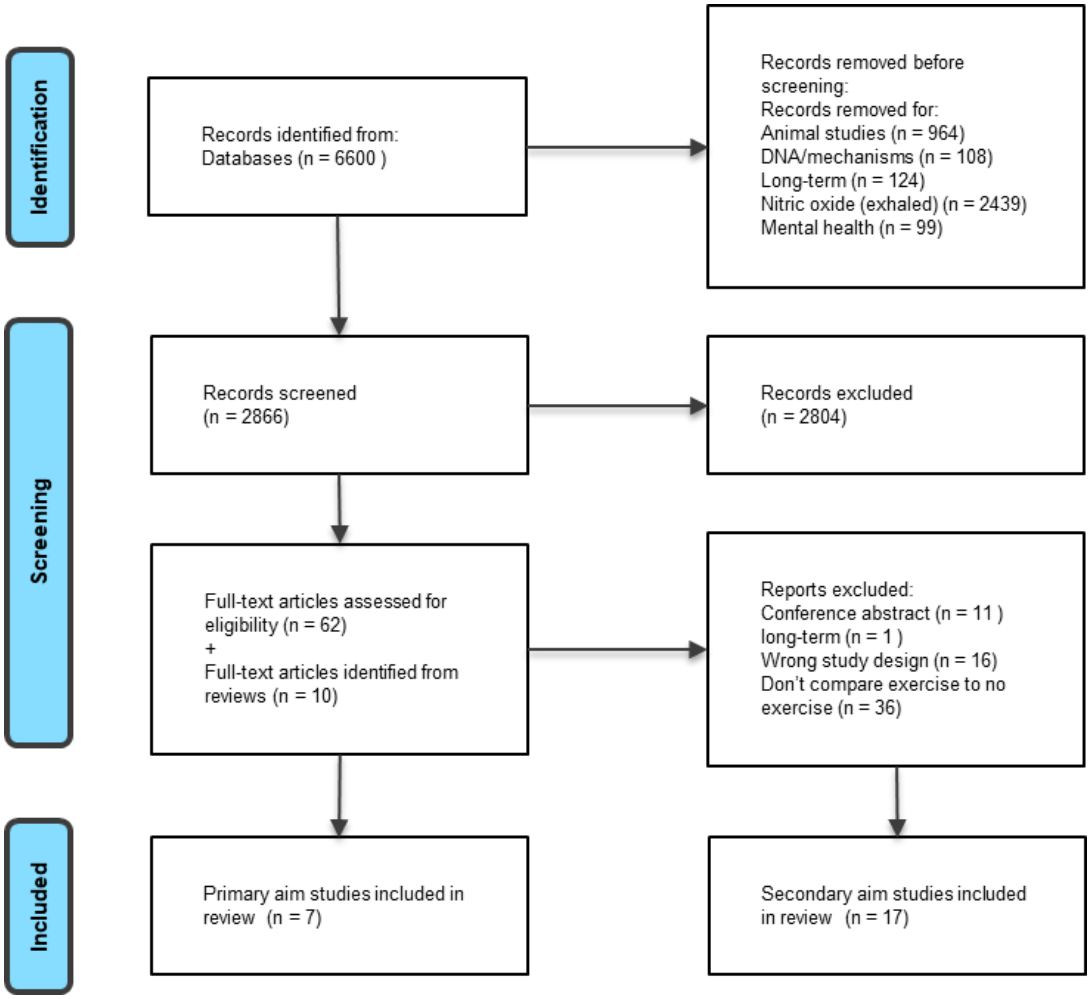

Figure 1: Process of identifying the studies that were included in this review

From the 24 studies, seven studies fitted the primary aim with six (Nwokoro et al., (2012); Kubesch et al., (2015a); Kubesch et al., (2015b); Matt et al., (2016); Giles et al., (2018); Marmett et al., (2022)) of them on healthy individuals and one (DeMeo et al., (2004) on patients with different chronic diseases. The remaining 17 studies fitted the secondary aim with 10 (Rundell, K. et al., (2007); Brauner, E. et al., (2008); Strak, M. et al., (2009); Bos, I. et al., (2011); Weichenthal, S. et al., (2014); Frampton, M. et al., (2015); Liu, W.T. et al., (2015); Cruz, R. et al., (2022); Tainio et al., (2016); Pasqua et al., (2018)) on healthy individuals (two were mathematical modelling studies) and 7 on people with chronic diseases such as COPD, asthma and coronary artery disease (CAD) (Pekkanen, J. et al., (2002); Lanki, T. et al., (2006); McCreanor, J. et al., (2007); Mills, N. et al., (2007); Sinharay, R. et al., (2018); Liu, L. et al., (2020); Syed, N. et al., (2021)). The majority of studies investigated adverse associations of health outcomes with exposure to particulate matter with a diameter less than or equal to 2.5 µm ($PM_{2.5}$) during exercising (Figure 2). Relatively few studies have been conducted on the health effects of exposure to O_3 and NO_2 while engaging in PA.

study/pollutants	PM_{10}	PM_{coarse}	$PM_{2.5}$	UFP	BC	NO_2	O_3	Other Pollutant Associations	Other Pollutants Measured
DeMeo, 2004, USA			✓						
Giles, 2018, Canada			x						
Marmett, 2022, Brazil						x	x		
Kubesch, 2015a, Spain	✓	✓	✓	x	x				NO_x
Kubesch, 2015, Spain	✓	✓	x	✓	✓			NO_x	
Matt, 2016, Spain	x	✓	x	x	x				NO, NO_x
Nwokoro, 2012, UK	x				✓				
Rundell, 2007, USA						x	x	PM_1	CO
Brauner, 2008, Denmark	x	x	x	x				PM_1	
Strak, 2009, Netherlands	✓							PNC	
Bos, 2011, Belgium	✓		✓		✓			soot	
Weichenthal, 2014, Canada			✓	✓	x	x	✓		
Frampton, 2015, USA							x		
Liu, 2015, Taiwan	x		✓						TVOCs
Pekkanen, 2002, Finland		x	✓	✓		✓		CO	
Lanki, 2006, Finland			✓					EC	
McCreanor, 2007, UK	x		x	✓		x		EC	
Mills, 2007, Sweden	✓			x		x			TVOCs, CO, NO_x
Sinharay, 2018, UK	x		✓	✓	✓	✓			
Liu, 2020, Canada			x			x	x		SO_2, CO
Syed, 2021, Canada			✓			x			
Cruz, 2022, Brazil	✓		✓			✓		NO	
Tainio, 2016, Global			✓						
Pasqua, 2018, Global	✓		✓						

UK DAQI: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Figure 2: Whether pollutants are associated with adverse health effects (✓ for yes, x for no) by study, with main studies in top section. Colour boxes relate to concentrations of DAQI pollutants in each study, where colour correspondents to the DAQI band of the concentrations.

Only one of the primary studies included in our report considered patients with chronic diseases and a control group; the other six studies were conducted on healthy individuals. Both men and women were included in four out of the seven primary studies, and three studies were conducted only on healthy men. The number of participants included in most of these studies was between 18-30 participants, but one study included 120 participants. Participants in three studies were of 18-60 years range and the other four studies included adults between 20-40 years old.

3.1 Health effects of air pollution while exercising compared to being at rest

Only seven studies have been identified that discussed the health effects of performing physical activity in air pollution compared to no physical activity in the same environmental conditions. Six studies looked at healthy individuals, two of these using the same group of individuals, and one study included some individuals with chronic diseases. From this small number of studies, it was suggested that undertaking physical activity in air pollution is still beneficial for health compared to being at rest.

In a study 28 young, healthy participants were exposure for 2 hours to low and high traffic-related air pollution (TRAP) while performing intermittent exercise in two outdoor locations in Barcelona, Spain, Kubesch et al., (2015a) reported that while PM may induce pulmonary and systemic inflammatory responses, there was no consistent evidence of an interaction

between TRAP and PA for any health outcomes. In other words, they found that even in highly polluted environments (Black carbon (μg/m^3): Low traffic = 8.59, High traffic = 60.82, UFP (particles/cm^3): Low traffic = 32992.75, High traffic = 164464.30, NO_x (ppb): Low traffic = 71.62, High traffic = 722.18, PM_{10} (μg/m^3): Low traffic = 67.79, High traffic = 129.68, $PM_{2.5}$ (μg/m^3): Low traffic = 30.03, High traffic = 80.76, PM_{coarse} (μg/m^3): Low traffic = 37.75, High traffic = 48.91), moderate PA still increased pulmonary function regardless of air pollution levels during PA. Although PA typically reduces inflammation, this study found that intermittent PA during air pollution exposure (low or high), was associated with increased lung inflammation and systemic inflammation markers interleukin-6, leucocytes and neutrophils counts compared to rest. Using the same group of participants, Kubesch et al., (2015b) found that exposure to traffic-related air pollution (same concentrations as the previous study) was associated with an increase in both systolic blood pressure (SBP) and diastolic blood pressure (DBP) at rest. They observed that intermittent PA (heart rate was 50 – 70%, PA: 15 min of cycling on a stationary bicycle alternating with 15 min of rest) generally attenuated the impacts from TRAP on SBP, but not in DBP. However, significant interactions specifically between PM_{10} (PM_{10} = 129.68 μg/m^3), or PM_{coarse} (PM_{coarse} = 48.91 μg/m^3), and PA on SBP was found, suggesting that PA during high levels of these air pollutants specifically may be key factors in the SBP increase. In a similar study design by the same study group (2 years after the previous studies), Matt et al. (2016), found that FEV_1/FVC and $FEF_{25–75\%}$ significantly increased with physical activity while increased exposure to PM_{coarse} (PM_{coarse} (μg/m^3) Low traffic = 27, High traffic = 41) without PA was associated with decreases in FEV_1 and FVC. They found that an increase in PA during exposure attenuated the immediate negative impacts of PM_{coarse} on peak expiratory flow (PEF) and also attenuated the delayed negative impacts of exposure on FVC.

In a cross-sectional study of 120 young men, Marmett et al., (2022), reported that outdoor PA did not represent an extra risk to health despite a higher exposure to O_3 concentration as compared to those in two other groups (O_3 concentrations: untrained (<2 exercise session/week for six months before the experimental trial) = 14.73 μg/m^3/8h, Indoor = 16.41 μg/m^3/8h, Outdoor = 26.85 μg/m^3/8h). Among 28 older (healthy or diagnosed with either COPD, asthma, angina, heart attack, heart failure, hypertension), Boston residents (mean age: 73 years), DeMeo et al., (2004) in an experimental study, found that there was a statistically significant effect of ambient particulate ($PM_{2.5}$) air pollution ($PM_{2.5}$ = 13.42 μg/m^3 (1 interquartile range)), decreasing oxygen saturation at rest and post-PA rest, but not during PA. The study did not consider in depth differences in impacts on O_2 saturation between resting exposure and post-PA resting exposure. Individuals taking β-blockers had a greater pollution related decrease in oxygen saturation at rest but, no other comparison was done in this study between individuals with chronic diseases and healthy individuals.

In a study of 18 healthy men (age 24.5 (6.2) yr. (mean (sd))) involving trials of 30-min low-intensity or high-intensity cycling or rest, in diesel exhaust (DE) and filtered air, Giles et al., (2018), determined that an increase in throat and chest symptoms (participants rated their symptoms on a questionnaire) was experienced with DE exposure (300 μg/m^3 of $PM_{2.5}$). However, those symptoms were not intensified by exercising in DE and the participants did not experience greater negative acute pulmonary and autonomic effects compared to not

exercising. A major implication from this study is that the evidence is not clear as to whether exercising vigorously on a highly polluted day is necessarily harmful to health.

On the other hand, in a study of 28 healthy London commuters, Nwokoro et al., (2012), found that the cyclists had an increased airway macrophage carbon and TNF-a compared to the non-cyclists, which indicated short-term inflammation in the cyclists. However, the authors recognised that it remains unclear whether cycling per se increased the airway macrophage carbon. The 24 hr BC exposure of the two groups was similar; however, the cyclists were exposed to higher concentrations (commuting BC (ng/m^3): cyclists = 3.256 x 10^5 ± 4.86 x 10^4, non-cyclists = 1.206 x 10^5 ± 3.26 x 10^4) during their commuting. Since non-cyclist sometimes walked to work, the increase in the cyclists could also be related to the intensity of the physical activity.

3.2 Health effects of short-term air pollution exposure while exercising (no control group)

3.2.1 Healthy Individuals

Liu et al., (2015) compared different commuting modes and found that walking mode could induce greater effects on decreased heart rate variability (HRV) indices (during 1hr morning commute (09:00 – 10:00)) compared to those in the other modes (electrically powered subway, a gas-powered bus, a gasoline-powered car) among 120 young, healthy participants. Weichenthal et al. (2014) found that among 58 physically active women in Montreal, Canada, adverse changes in blood pressure, cardiac autonomic modulation, and/or vasomotor function during cycling in routes with different traffic intensity, was associated with short-term exposure to traffic. Moreover, the authors adjusted their models for continuous measures of 24-hour or 5-day mean regional ambient concentrations of NO_2, O_3, or $PM_{2.5}$ and their findings suggest that regional air pollution concentrations prior to the study (24hr median $PM_{2.5}$ of 11.5 µg/m^3, O_3 of 26.4 ppb and 5-day median $PM_{2.5}$ of 13.5 µg/m^3, O_3 of 26.5 ppb) may amplify the impact of short-term personal $PM_{2.5}$ or O_3 exposures on cardiovascular or autonomic function. However, it should be noted that measurements from regional monitors were poorly correlated with personal measurements in this study. In a study of 16 healthy male intercollegiate athletes involved in 30 min running (85 – 90% of maximal heart rate) in ambient conditions either on an inner campus loop free of auto/truck traffic (5309 ± 1942 particles/cm^3) or on a soccer field adjacent to a major highway (143,501 ± 58,565 particles/cm^3) Rundell et al. (2007), found that, after exercising in high concentrations of PM_1 , basal vasoconstrictive response as well as impaired flow-mediated dilation (FMD) in the brachial artery was identified, but not after exercising in low concentrations of PM_1. Moreover, they observed a decrease in the reperfusion slope after ischemia in the high concentrations of PM_1 exposure trials, suggesting a compromised arteriolar flow.

Some studies showed that there could be immediate, but also delayed, health effects of performing PA in air pollution. Bos et al. (2011), found that among 38 fit, non-asthmatic volunteers (female = 26%), serum Brain-Derived Neurotrophic Factor (BDNF – a neurotrophine) concentrations significantly increased after exercising in the air-filtered room (PM_{10} = 7.7 µg/m^3, $PM_{2.5}$ = 2.0 µg/m^3, UFP = 496 particles/cm^3), compared to no increase after

exercising near the major traffic route (PM_{10} = 64.9 µg/m^3, $PM_{2.5}$ = 24.6 µg/m^3, UFP = 28,180 particles/cm^3). Frampton et al. (2015), while alternating 15-min periods of rest and PA on a bicycle ergometer (target minute ventilation 25 L/min/m2 body surface area) in 24 healthy adults, did not find early acute adverse cardiovascular events (altered vascular or cardiac function) related to ozone exposure (filtered air, 100 ppb ozone or 200 ppb ozone).

On the other hand, Strak et al. (2009), observed in 12 healthy adults (8 female and 4 male) that 6hr after exposure, ultrafine particles and soot (weighted soot concentration from PM_{10} filters) during cycling was weakly associated with an increase in exhaled NO (FE_{NO}), indicative of airway inflammation, and also associated with decrements in lung function (an increase in particle number concentration of 40000 particles/cm^3 was associated with a 15% increase in FE_{NO} and a 15 x 10^{-5}/m increase in soot it was associated with a 1 – 4.5% decrease in all measured lung function parameters 6 h after cycling). However, no negative associations between exposure and changes in lung function parameters were found immediately after cycling.

Brauner et al. (2008), reported that in 29 participants (20 men and 9 women) physical activity (90 minutes of PA on an ergometer bicycle included as a factor to elucidate potential interactions) significantly and independently decreased haemoglobin and red blood cell count levels, but had no effect on the other biomarkers. Exposure to air pollution particles at outdoor concentrations was not associated with any of the study biomarkers. Cruz et al. (2022), determined in 15 healthy adult men that high-intensity interval exercise (HIIE) during traffic related air pollution (TRAP) exposure increased IL-6 secretion and decreased IL-10 and the IL-10/TNF-a ratio. Moreover, disturbances in metabolic pathways related to energy supply, and post-PA acute decrease of systolic blood pressure was observed. These findings suggested that TRAP potentially attenuates health benefits relating to HIIE however there is no control group to compare against.

3.2.2 Individuals with chronic diseases

A study of 60 people with mild to moderate asthma walking on a busy road with high particulate and NO_2 air pollution (Oxford Street) and a nearby park (Hyde Park) found associations of the degree of traffic exposure with poor lung function in asthma (McCreanor et al., 2007). The changes were associated most consistently with exposures to ultrafine particles and elemental carbon, pollutants that are largely emitted from traffic. The study was repeated with patients with COPD, ischaemic heart disease and healthy controls (Sinharay et al., 2018). Participants with COPD reported more cough, sputum, shortness of breath, and wheeze after walking down Oxford Street compared with Hyde Park. Health benefits (increase in lung function and a decrease in pulse wave velocity and augmentation index) observed during the walk in the park were not seen when walking along Oxford Street, and in participants with COPD, lung function measures actually decreased. Syed et al. (2021), found that 11 healthy control participants experienced greater negative effects of exposure to TRAP during PA, compared to former smokers, 9 with and 9 without COPD.

Liu et al. (2019) found that among patients with implanted cardioverter defibrillators, reducing air pollution exposure may reduce adverse cardiovascular effects (they measured blood pressure, oxygen saturation and pulse rate), while daily mild PA (walk outdoor for 30 mins or indoor PA if outdoor air pollution was high) may benefit cardiovascular function. Several further studies involved PA and exposure, but did not compare PA to no PA. Both Mills et al. (2007) and Pekkanen et al., (2002) in separate studies observed an association between air pollution and the risk of PA-induced ST-segment depression among subjects with coronary artery disease (CAD). Mills et al. (2007), found that exposure to diesel exhaust promoted myocardial ischemia and inhibited endogenous fibrinolytic capacity in men with stable coronary heart disease. Pekkanen et. al. (2002), found through ambulatory ECG that the effect of particulate air pollution on cardiovascular morbidity during a 6-minute exercise on bicycle ergometer was at least partly mediated through increased susceptibility to ischemia and provided a plausible biological link between ambient levels of particulate matter and risk of mortality and mortality attributable to ischemic heart disease. Moreover, Lanki et al. (2006), following on the Pekkanen et al., (2002), study, determined that $PM_{2.5}$ originating from local traffic and long-range transport were associated with ST-segment depressions.

3.2.3 Mathematical modelling studies

Tainio et al. (2016), estimated the health risks of PM2.5 y converting background PM2.5 concentrations to travel mode specific exposure concentrations, and by taking into account ventilation rate whilst being active. They modelled that even up to 1 h 15 min of cycling and 10 h 30 min of walking per day in healthy adults would still lead to net reduction in all-cause mortality at areas with very high $PM_{2.5}$ concentrations (100 $\mu g/m^3$). The authors calculated a tipping point (at which PA becomes detrimental) in average urban areas with $PM_{2.5}$ concentrations of 22 $\mu g/m^3$ would only be reached after 7 h of cycling and 16 h of walking per day in healthy adults. The authors concluded that the benefits of PA by far outweigh the risks from air pollution under the global average urban background $PM_{2.5}$ concentration (22 $\mu g/m^3$).

Pasqua et al. (2018), recruited 116 volunteers to perform maximal incremental running test in a controlled temperature room and only extracted the ventilation data from the running tests that they then used to predict the total ventilation of two 30 min hypothetical situations (rest and continuous moderate exercise). The WHO air pollution data for 2016 was used to calculate the inhaled PM2.5 and PM10 for each considered city. They modelled that in the cleanest cities, the PA benefits would continue increasing even after 90 min of aerobic PA, however in the dirtiest cities the health benefits could be mitigated after only 15 min (Dirtiest Cities PM_{10}: 318 – 594, $PM_{2.5}$:128 – 149 $\mu g/m^3$, Cleanest Cities PM_{10}: 4 – 7, $PM_{2.5}$: 1.6 – 4 $\mu g/m^3$).

3.3 Outdoor – indoor relationship

An important consideration for exercising during pollution episodes is determining whether exercising indoors could be an effective alternative. Indoor air pollution originates from both

sources within the indoor environment and the penetration of outdoor pollutants through natural and mechanical ventilation. A report on Indoor Air Quality by Defra's Air Quality Expert Group (AQEG) reported that the indoor/outdoor (I/O) ratios for particulate matter were typically less than 1 (PM_{10} – 0.6, PM_1 – 0.8), with similar findings for NO_2 (0.3-0.8) and O_3 (0.3-0.7) (AQEG, 2022). In addition, there are other considerations for individuals at greater risk from exposure to pollutants (e.g., people with asthma (Delfino, 2002)) that are much more prevalent indoors such as volatile organic compounds as a result of mould and chemical interactions. The report also notes that mechanical ventilation is an important consideration for improving air quality in indoor spaces, as lower ventilation rates cannot adequately replace the stale air with outdoor air.

There are a limited number of studies regarding indoor air quality structured within the context of short-term air pollution episodes. Shrestha et al. (2019) observed indoor and outdoor concentrations of air pollutants in low-income homes during two wildfire seasons in Denver, Colorado. Their findings showed a 4.6:1 I/O ratio for $PM_{2.5}$ due to long-range wildfire plumes, while homes closer to roads had higher concentrations of black carbon, carbon monoxide and nitrogen dioxide. In addition, it was observed that homes with their windows open for more than 12 hours a day had an indoor black carbon 2.4 times higher than those with windows closed. The findings suggest that natural ventilation may increase the prevalence of particulates within the homes during air pollution episodes.

Studies of school gyms in Prague found that particulate matter (< 2.5 microns) ($PM_{2.5}$) had infiltrated from outdoor sources (traffic-related origin) (Braniš, Šafránek, & Hytychová, 2011). Principal component analysis also highlighted human activity as a source of PM, due to resuspension. The findings suggest that not only can pollution infiltrate from outdoor sources, but PA within the indoor environment can lead to an increase of fine particulates suspended within the air. These findings were supported by Buonanno et al. (2012), who also investigated PM (PM_1, $PM_{2.5}$ & PM_{10}) within school gyms during physical activities in Italy. When under natural ventilation, the average coarse particle ($PM_{10-2.5}$) concentrations across the study sites were 4.8 (± 2.0) times higher than the outdoor concentrations.

As far as the authors are aware, only one study has attempted to determine the impact of indoor PA as an intervention for outdoor PA during high pollution episodes by looking at adults exercising outdoors everyday (control group, n = 35) or either indoors or outdoors (intervention group, n = 37) based on the Air quality health index (Ontario, Canada) (if AQHI ≥ 5 they exercised indoors) (Stieb et al., 2021). While producing evidence that some outcomes (such as heart rate, heart rate variability, urinary malondialdehyde for the control group) were associated with higher air pollution days, the study interpretation is limited by a lack of days with an intervention (n=2) due to the threshold for triggering an intervention being too high.

3.4 Quality Assessment

We have assessed the air pollution exposure and measurement methods of the primary studies.

Kubesch et al., (2015a), Kubesch et al., (2015b) and Matt et al., (2016) used the same study design at the same location. Their exposure and air pollution measurements methods are robust and include an optical particle counter CPC 3007 from TSI for UFP counts, a NO_x analyser for nitrogen oxides (NO_x), a Harvard Impactor (HI) for $PM_{2.5}$ and PM_{10} (gravimetric analysis was conducted in a specialised laboratory) and a portable aethalometer for black carbon (BC). Marmett et al., (2022), used single passive diffusion tubes to measure O_3 and NO_2. This could introduce issues in airflow when measuring indoors compared to outdoors. They didn't provide any uncertainties in their measurements. Moreover, as this was measured over a week, it is difficult to associate exposure with PA. DeMeo et al, (2004), used a government air quality monitoring network, 1 km away from the study site to monitor $PM_{2.5}$ and CO and another site 5 km away for O_3, NO_2 and SO_2. The temporal resolution of the air pollution data (hourly) didn't match the experimental design (5 continuous 5-minute intervals). Furthermore, it is difficult to assess uncertainty in the study as they did not specify whether the monitoring sites are road sites/ urban/ background etc. Nwokoro et al., (2012), used portable aethalometers, a well-established method for measuring BC. Uncertainties could be introduced in the measurement due to airflow dynamics of cyclists compared to non-cyclists. Giles et al., (2018), used a robust method (Tapered Element Oscillating Microbalance (TEOM; Model 1400a) to measure PM mass concentrations and a TSI Scanning Mobility Particle Scanner (Model 3936) classified the particle size distribution between 2.5 nm and 1000 nm) to measure air pollution, however they didn't discuss whether air was well mixed in the chamber during the study.

All studies used well-established methods to measure the air pollution exposure of the participants, however, in 2 studies the instrumentation setups could introduce issues with airflow which will lead to uncertainties in the measurements (Nwokoro et al., (2012); Marmett et al., (2022)).

Moreover, key limitations in the primary aim studies include that sample sizes among all these studies were small and most were restricted to healthy persons only. One study included individuals with chronic diseases however they didn't analyse based on the disease. Also, conducting real-world studies have some inherent limitations including many uncontrollable, day-to-day variations and potentially greater uncertainties in exposure estimates.

4 Discussion

The primary aim of this report was to investigate and report evidence on the health impacts of short-term air pollution exposure while performing PA compared to no PA. The discussion is divided into different sections to account for the different study types. Section 4.1. covers the primary aim of this review, which involves the comparison of the health effects in air pollution between PA and no PA. In section 4.2 the studies that investigated the health effects of PA in air pollution (but with no control group of no PA) are discussed and how relevant the DAQI advice is to users performing physical activity. A separate section showing the importance of chamber studies and the need to better review those studies is included. Moreover, a section on outdoor – indoor concentration relationships is discussed as indoor

exposures likely relate to but are not the same as outdoor exposures. The study limitations along with future research needs are discussed and finally some policy information based on the review are presented.

4.1 Health effects of air pollution while exercising compared to being at rest

Section summary:

- Overall quantity of evidence based on only seven studies is very low, precluding any firm conclusion;
- Current limited evidence suggests that short-term exposure to air pollution while engaging in physical activity does not seem to negate the health benefits of the latter, at least among healthy young adults;
- A study found that compared to rest, intermittent PA (heart rate = 50 – 70%) attenuates the traffic related increase in systolic blood pressure and has beneficial effects on pulmonary function in healthy adults;
- One study suggested that increased outdoor O_3 concentrations did not present any additional risks to health compared to exercising indoors in lower concentrations and another study reported that diesel exhaust (DE) exposure while exercising did not increase symptoms experienced during resting exposure to DE;
- One study reported that ambient particulate air pollution exposure decreases oxygen saturation more when at rest than the same exposure does during PA in a population of free-living older individuals which included some individuals with long term diseases;
- One study showed high intensity PA (cycling) in the presence of BC may be associated with an increase in serum cytokines (TNF-a), an inflammatory marker.

The overall quantity of evidence based on only seven studies (three of which from the same research group based at Barcelona, Spain) is very low, precluding any firm conclusions. Nonetheless, current limited evidence suggests that short-term exposure to air pollution while engaging in physical activity does not seem to negate the health benefits of the latter, at least among healthy young adults. However, this needs to be validated by future studies and it is important to note that there are currently no studies available in this area of research among vulnerable populations such as those with long-term health conditions.

Although the number of PA vs. no PA studies means that the evidence base is very limited, and that each study has several noted limitations, we provide a tentative summary of results. Compared to rest, intermittent PA (heart rate = 50 – 70%) attenuates the traffic related increase in systolic blood pressure and has beneficial effects on pulmonary function in healthy adults. One study reported that ambient particulate air pollution exposure decreases oxygen saturation more when at rest than the same exposure does during PA in a population of free-living older individuals which included some individuals with long term diseases. However, one study reported that exposure to diesel exhaust had no additional negative effects while

exercising in terms of symptoms. Additionally, one study showed that higher O_3 concentration exposure during PA did not represent an additional health risk. One study that considered prior exposures as well as exposure during PA, suggested that associations between various pollutant exposures and respiratory measures were modified both by the level of PA during traffic-related air pollutants (TRAP) exposure and by the level of participant pre-exposure to TRAP before PA. One study showed high intensity PA (cycling) may be associated with an increase in serum cytokines (TNF-a), an inflammatory marker.

4.2 Health effects of short-term air pollution exposure while exercising (no control group)

While these studies did not investigate the role of physical activity per se regarding health effects of short-term air pollution, they nonetheless provided important context for discussion.

Section summary:

- Most studies suggest that exposure to higher particulate matter levels is associated with adverse pulmonary or cardiovascular health effects;
- In people with chronic diseases, it was determined that higher air pollution during PA was associated with larger negative effects on health;
- Minimizing TRAP exposure during high intensity exercise (HIIE) is important in order to mitigate these potential adverse health outcomes;
- In some studies, negative health effects during exercise were observed in air pollution levels as low as the current LOW – MID level DAQI bands (not directly related – see paragraph below);
- It is not possible to draw firm conclusions to inform behavioural advice from these studies, as it is unclear whether the observed effects are due to a combination of the physical activity and the air pollution exposure or whether it was solely due to the air pollution exposure since there is no control group.

Secondary studies used experimental and epidemiological methodologies. PA was included or used in these studies in three different ways: to maintain exposure, to evaluate cardiorespiratory fitness, and to elucidate potential interactions. The results of the secondary studies suggested that an increase in air pollution negatively affected the cardiopulmonary system. Most studies suggest that exposure to higher particulate matter levels is associated with adverse pulmonary or cardiovascular health effects. However, most of the studies did not take into account whether these effects are due to the dose of physical activity or the exposure level during air pollution episodes as they did not include a control group to compare against. Only one study focused on PA intensity and revealed that TRAP potentially attenuated health benefits relating to high-intensity exercise, which led to impaired anti-inflammatory balance. In people with chronic diseases, it was determined that higher air

pollution during PA was associated with larger negative effects on health. The studies identified cannot be directly related to the DAQI as most of the studies only measure exposure during the PA time. For example, particulate DAQI levels are based on 24hr average which may not reflect the pollution levels during the specific PA exposure period. For people to be able to get the best advice possible out of the DAQI, the system needs be based on time-frames more appropriate for engaging in physical activity such as hourly averages rather than daily. In some studies, negative health effects during exercise were observed in air pollution levels as low as the current LOW – MID level DAQI bands (though as already mentioned, not directly comparable). It is unclear whether the health effects are due to a combination of the physical activity and the air pollution exposure or whether it was solely due to the air pollution exposure since there is no control group.

4.3 Chamber studies

This section gives a brief summary of chamber studies outside the scope of but related to this review. The studies were separated out due to the fact that the majority of chamber studies did not fit our PECO. Most chamber studies used exercise to increase the ventilation rate and their authors were not investigating how exercising in polluted or filtered environments affected health but rather how the pollution affected health. However, they could provide useful information and we suggest that a comprehensive literature review on the chamber studies should be done.

Mudway and Kelly, (2004), in a review of 23 chamber studies (all studies but 2 included exercising during exposure) investigated the magnitude of airway inflammation from inhaled ozone dose in healthy adults. They demonstrated that there is a linear exposure-response relationship between ozone dose and neutrophilia in alveolar lavage samples. Moreover, they found that dose threshold for the early (0-6 hours) inflammatory response was lower (645 [408–883] mg/m^2) than that for the late (18-24 hours) inflammatory response (810 [491–1,130] mg/m^2) (note that the units are calculated from concentration, inhalation volume rate, exposure time and body surface area). The authors also stated that healthy individuals are likely to develop acute airway inflammation if performing relatively mild exercise for prolonged periods during ozone episodes.

Delvin et al., (2012), in a study of 23 young healthy adults intermittently exercised for two hours in 300 ppb ozone, found an increase in vascular markers of inflammation, changes in markers of fibrinolysis and markers that affect autonomic control of heart rate and repolarization; all of these were measured immediately after and 24 hours after exposure. Moreover, Frampton et al., (2015), after exercising 24 young healthy adults for three hours in 100 ppb and 200 ppb of ozone, found that there was a dose-dependent blunting of increase in blood pressure following exercise at four hours after exposure.

In the REVIHAAP Project report (WHO, (2021)) some chamber studies are referenced that showed some health effects when people exercising were exposed to air pollution. For instance, Kim et al., (2011), reported that there was a significant and acute decrease in FEV_1

and increased neutrophilic inflammation of the airways after exposing 59 healthy exercising young adults to 0.06 ppm (60 ppb) ozone for 6.6 hours under controlled chamber conditions. Furthermore, in the REVIHAAP report it was reported that 5–30% of asthmatics during 5–10 minutes of exercise could experience moderate or greater decrements in lung function when exposed to concentrations of 0.2 – 0.3 ppm (200 – 300 ppb) of SO_2.

Gong et al., (2003), exposed 12 healthy and 12 asthmatic volunteers in concentrated ambient particles (CAP) (average $PM_{2.5}$ – 174 μg/m^3) and to filtered air. They determined that cardiovascular symptoms (such as decrease of columnar cells, slight changes in certain mediators of blood coagulability and systemic inflammation and small increases in parasympathetic stimulation of heart rate variability) increased slightly with exposure to CAP in both groups. A decrease in systolic blood pressure in asthmatics and an increase in the healthy volunteers was observed during CAP exposure, relative to filtered air. In another study, Gong et al., (2004), 13 elderly volunteers with COPD and 6 healthy adults were exposed for 2 hours to 200 μg/m^3 concentrated ambient particles (CAP) (and filtered air) with intermittent mild exercise. An unexpected outcome found in this study was that healthy individuals were more susceptible than the individuals with COPD. Post exposure, they observed an increase in ectopic heartbeats in healthy individuals and a decrease in the individuals with COPD compared to preexposure measurements. Moreover, a significant negative effect on arterial oxygenation, an increase in peripheral blood basophils and lower heart rate variability were observed in the healthy individuals after CAP but not in the individuals with COPD. In both groups, red cell counts increased slightly 1 day after exposure to FA but not to CAP.

In an attempt to determine the respiratory impacts of inhaled PM combined with co-pollutants, Gong et al., (2005), exposed 6 healthy individuals and 18 individuals with COPD (mean age 71 yr) for 2h with a 15 min exercise period every half hour. The individuals were exposed on separate days to (a) filtered air; (b) 0.4 ppm (400 ppb) of NO_2; (c) CAP ($PM_{2.5}$) at 200 μg/m^3 and (d) with CAP and NO2 together (0.4 ppm of NO_2 and CAP ($PM_{2.5}$) at 200 μg/m^3). They determined that older adults exposed to urban fine particles may experience acute small-airways dysfunction with impaired gas exchange. They found small but statistically significant decrements on maximal mid-expiratory flow and arterial O_2 saturation (greater in healthy individuals) and decreases in percentages of columnar epithelial cells associated with CAP exposure. They found that the respiratory effect is primarily driven by the PM since co-exposure to NO_2 did not significantly enhance the response. Last but not least, they reported that the respiratory effect may be related to efficient penetration and deposition of inhaled toxic particles in distal small airways since healthy individuals are more susceptible.

4.4 Limitations and Future studies

- The number of studies addressing the question of interest (i.e. primary studies) was very limited. Therefore, more research is needed to determine the effects of PA vs no PA in air pollution.

- The low sample size in the included studies is the main limitation. The sample size of the participants should be increased, while including more heterogeneous populations.
- Most of the studies are experimental ones in healthy individuals with small sample sizes. Considering the study types, we recommend that more studies be conducted in healthy individuals, people with chronic disease and those who may be vulnerable e.g. children, elderly, those with regular strenuous outdoor PA (for work or leisure).
- Blinding of participants and those assessing outcomes, should be considered in the study methods to design studies with higher quality, although this may not be possible e.g. it would be possible to smell exposures to diesel exhaust.
- Studies examining the effects of air pollution both without PA and with PA should be conducted. We were only able to identify seven studies, only one of which examined individuals with chronic diseases. Moreover, there is a significant lack of research evaluating different PA doses (based on intensity and duration) across a wide range of exposure to air pollution.
- In addition, the effects of PA in different air pollutants should be examined, as the current results mainly relate to PM and are insufficient to guide the policies.
- Future work to replicate the study design of Stieb et al., on the impact of indoor PA as an intervention for outdoor PA during high pollution episodes would be useful; the study design could be improved by lowering the intervention trigger threshold and by considering more outcomes such as disease markers and risk of exacerbating existing chronic diseases. These studies could help establish the most appropriate thresholds to use for guidance on indoor exercising as an intervention for elevated outdoor air pollution. Intervention studies could also be designed to look at benefits of indoor/outdoor exercise for a range of vulnerable groups.

4.5 Policy-relevant information

- The evidence is limited, with very few studies with highly variable study designs and definite conclusions cannot be made. However, 5 out of the 7 studies identified comparing at rest individuals to individuals exercising in air polluted environments suggest that there are benefits to health when exercising. Further, **physical activity was found to attenuate the negative effects of air pollution** on respiratory measures even in highly polluted environments (in the very high bands of DAQI), moderate PA had beneficial effects on pulmonary function **in healthy individuals** compared to not exercising.
- Exercising in indoor spaces could lead to higher exposure to air pollution depending on the room ventilation type and PM resuspension due to human activity.
- Based on two linked studies, **short-term exposure to high traffic** pollution compared to lower exposure may **offset some of the short-term beneficial cardiopulmonary effects** of walking for **healthy individuals** and individuals with **ischemic heart diseases and COPD**. Greater reductions in lung function are observed in people with **asthma** when walking in high polluted roads compared to parks. Moreover, these studies revealed that the **higher the pollution levels** are while engaged in PA, the **larger the**

negative effects will be on health. Negative health effects were seen in the low DAQI bands.

- The air pollution levels of cities should be considered for physical activity recommendations. The two mathematical modelling studies suggest that the health benefits of PA will be attenuated in highly polluted cities with pollution levels in the very high DAQI band.
- The DAQI is not directly comparable with measurements used in identified studies, which were mainly at the time of the PA. For example, in the DAQI particulates are a 24hr average which might not reflect the pollution levels at the time of PA. Five studies, negative health effects (reduced lung function, increased inflammatory markers etc.) during PA (walking, cycling etc.) were observed in air pollution levels as low as the current **LOW – MID level DAQI** bands (as already mentioned, not directly comparable). No comparison with those not exercising was made in these studies
- Future research funding in this area should prioritise experimental studies in real world conditions, spanning a range of exposure levels, pollutant mixes, and physical activity levels, and include diverse groups of participants including with chronic conditions (see PECO table for identified vulnerable groups and conditions).

5 Conclusions

In this report, we aimed to determine the health effects of physical activity in the presence of air pollution. Few studies were available, and most studies only look at exercising in air pollution without comparing the results to a control group at rest. Therefore, more research is needed to determine the effects of PA vs no PA in air pollution.

The seven studies identified that compared the health effects of air pollution while performing physical activity to the health effects at rest mainly showed that there are benefits to physical activity compared to no physical activity, at least in healthy individuals (six of seven studies). Specifically, the studies showed that physical activity has beneficial effects on pulmonary function compared to rest and suggested that physically active individuals might have a lower risk of developing cardiovascular and metabolic diseases even if the activity was taken in the presence of air pollution. Increase of PA was found to reduce the immediate negative effects of PM upon peak expiratory flow (PEF) and the delayed negative effects of PM upon FVC. Along with the beneficial effects on pulmonary function, intermittent PA was found to attenuate the traffic related increase in systolic blood pressure. Moreover, one study looking at healthy individuals found that DE exposure while exercising did not exacerbate any symptoms experienced during rest. Only one study (Nwokoro et al. (2012)) showed that high intensity PA (cycling) in the presence of BC maybe associated with increase in serum cytokines (TNF-a).

We identified 17 studies looking only at the health effects of air pollution while PA was undertaken (i.e. no outcome measurement at rest). These found associations of air pollution with adverse health effects. 15 out of the 17 studies found associations of exposure to particulate matter levels with health effects while doing PA. Moreover, studies showed that

in people with chronic diseases, higher air pollution while performing PA could have larger negative effects on their health compared to exercising in environments with lower air pollution. For example, greater reductions in lung function were observed in people with asthma when walking in a high polluted road compared to a park (McCreanor et al., (2007). Furthermore, a study looking at high intensity exercising determined that the intensity of physical activity could have an effect on health effects. Minimizing TRAP exposure during high intensity exercise (HIIE) is important in order to mitigate these potential adverse health outcomes.

More studies are needed to be able to make definite conclusions and provide the public with better information and advice during pollution events. Moreover, a comprehensive review on chamber studies is needed to get a better understanding of the health effects in control environments, as the limited studies reviewed in this report suggest that there are adverse health effects while exercising in air pollution. Any updates to the DAQI should consider providing information to people about air pollution in time-frames (based on hourly advice instead of 24 hr averaged DAQI) appropriate for engaging in physical activity.

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6 References

AQEG: Indoor Air Quality. In Indoor Air Quality (Public version, mirrored from www.UK-Air.gov.uk, p. 142). Department for the Environment, Food and Rural Affairs, https://doi.org/10.5281/zenodo.6523605, 2022

Bos, I., Jacobs, L., Nawrot, T. S., de Geus, B., Torfs, R., Int Panis, L., Degraeuwe, B., and Meeusen, R.: No exercise-induced increase in serum BDNF after cycling near a major traffic road, Neuroscience Letters, 500, 129-132, https://doi.org/10.1016/j.neulet.2011.06.019, 2011.

Braniš, M., Safránek, J., and Hytychová, A.: Indoor and outdoor sources of size-resolved mass concentration of particulate matter in a school gym-implications for exposure of exercising children, Environ Sci Pollut Res Int, 18, 598-609, 10.1007/s11356-010-0405-0, 2011.

Brauner, E. V., Moller, P., Barregard, L., Dragsted, L. O., Glasius, M., Wahlin, P., Vinzents, P., Raaschou-Nielsen, O., and Loft, S.: Exposure to ambient concentrations of particulate air pollution does not influence vascular function or inflammatory pathways in young healthy individuals, Particle and Fibre Toxicology, 5, doi:https://dx.doi.org/10.1186/1743-8977-5-13, 2008.

Buonanno, G., Fuoco, F., Marini, S., Stabile, L.: Particle resuspension in school gyms during physical activities. Aerosol and Air Quality Research, 12(5), pp. 803-813, 2012

Cruz, R., Koch, S., Matsuda, M., Marquezini, M., Sforca, M. L., Lima-Silva, A. E., Saldiva, P., Koehle, M., and Bertuzzi, R.: Air pollution and high-intensity interval exercise: Implications to anti-inflammatory balance, metabolome and cardiovascular responses, The Science of the total environment, 809, doi:https://dx.doi.org/10.1016/j.scitotenv.2021.151094, 2022.

DeFlorio-Barker, S., Lobdelle, D. T., Stone, S. L., Boehmer, T., and Rappazzo, K. M.: Acute effects of short-term exposure to air pollution while being physically active, the potential for modification: A review of the literature, Preventive medicine, doi:https://dx.doi.org/10.1016/j.ypmed.2020.106195, 2020.

DeMeo, D. L., Zanobetti, A., Litonjua, A. A., Coull, B. A., Schwartz, J., and Gold, D. R.: Ambient air pollution and oxygen saturation, American Journal of Respiratory and Critical Care Medicine, 170, doi:https://dx.doi.org/10.1164/rccm.200402-244OC, 2004

European Environment Agency (2022). Air pollution: how it affects our health – European Environment Agency. Available at: https://www.eea.europa.eu/themes/air/health-impacts-of-air-pollution. (Accessed: 28 March 2023)

Frampton, M. W., Pietropaoli, A., Dentler, M., Chalupa, D., Little, E. L., Stewart, J., Frasier, L., Oakes, D., Wiltshire, J., Vora, R., and Utell, M. J.: Cardiovascular effects of ozone in healthy subjects with and without deletion of glutathione-S-transferase M1, Inhalation Toxicology, 27, doi:https://dx.doi.org/10.3109/08958378.2014.996272, 2015.

Garcia, L., Pearce, M., Abbas, A., Mok, A., Strain, T., Ali, S., Crippa, A., Dempsey, P. C., Golubic, R., Kelly, P., Laird, Y., McNamara, E., Moore, S., de Sa, T. H., Smith, A. D., Wijndaele, K., Woodcock, J., and Brage, S.: Non-occupational physical activity and risk of cardiovascular disease, cancer and mortality outcomes: a dose–response meta-analysis of large prospective studies, British Journal of Sports Medicine, bjsports-2022-105669, 10.1136/bjsports-2022-105669, 2023.

Giles, L. V., Carlsten, C., and Koehle, M. S.: The pulmonary and autonomic effects of high-intensity and low-intensity exercise in diesel exhaust, Environmental Health, 17, 87, 10.1186/s12940-018-0434-6, 2018.

Delfino, R. J.: Epidemiologic evidence for asthma and exposure to air toxics: linkages between occupational, indoor, and community air pollution research, Environ Health Perspect, 110 Suppl 4, 573-589, 10.1289/ehp.02110s4573, 2002.

Devlin, R. B., Duncan, K. E., Jardim, M., Schmitt, M. T., Rappold, A. G., and Diaz-Sanchez, D.: Controlled exposure of healthy young volunteers to ozone causes cardiovascular effects, Circulation, 126, doi:https://dx.doi.org/10.1161/CIRCULATIONAHA.112.094359, 2012.

Frampton, M. W., Pietropaoli, A., Dentler, M., Chalupa, D., Little, E. L., Stewart, J., Frasier, L., Oakes, D., Wiltshire, J., Vora, R., and Utell, M. J.: Cardiovascular effects of ozone in healthy subjects with and without deletion of glutathione-S-transferase M1, Inhalation Toxicology, 27, doi:https://dx.doi.org/10.3109/08958378.2014.996272, 2015.

Gong Jr, H., Linn, W. S., Sioutas, C., Terrell, S. L., Clark, K. W., Anderson, K. R., and Terrell, L. L.: Controlled exposures of healthy and asthmatic volunteers to concentrated ambient fine particles in Los Angeles, Inhalation Toxicology, 15, doi:https://dx.doi.org/10.1080/08958370304455, 2003.

Gong Jr, H., Linn, W. S., Terrell, S. L., Anderson, K. R., Clark, K. W., Sioutas, C., Cascio, W. E., Alexis, N., and Devlin, R. B.: Exposures of elderly volunteers with and without chronic obstructive pulmonary disease (COPD) to concentrated ambient fine particulate pollution, Inhalation Toxicology, 16, doi:https://dx.doi.org/10.1080/08958370490499906, 2004.

Gong Jr, H., Linn, W. S., Clark, K. W., Anderson, K. R., Geller, M. D., and Sioutas, C.: Respiratory responses to exposures with fine particulates and nitrogen dioxide in the elderly with and without COPD, Inhalation Toxicology, 17, doi:https://dx.doi.org/10.1080/08958370590904481, 2005.

Hahad, O., Kuntic, M., Frenis, K., Chowdhury, S., Lelieveld, J., Lieb, K., Daiber, A., and Münzel, T.: Physical Activity in Polluted Air-Net Benefit or Harm to Cardiovascular Health? A Comprehensive Review, Antioxidants (Basel), 10, 10.3390/antiox10111787, 2021.

Health Effects Institute: State of Global Air 2020. Special Report. Boston, MA:Health Effects Institute, 2020.

Kim, C. S., Alexis, N. E., Rappold, A. G., Kehrl, H., Hazucha, M. J., Lay, J. C., Schmitt, M. T., Case, M., Devlin, R. B., Peden, D. B., and Diaz-Sanchez, D.: Lung function and inflammatory responses in healthy young adults exposed to 0.06 ppm ozone for 6.6 hours, Am J Respir Crit Care Med, 183, 1215-1221, 10.1164/rccm.201011-1813OC, 2011.

Kim, S. R., Choi, S., Keum, N., and Park, S. M.: Combined Effects of Physical Activity and Air Pollution on Cardiovascular Disease: A Population-Based Study, Journal of the American Heart Association, 9, e013611, doi:10.1161/JAHA.119.013611, 2020.

Kubesch, N., De Nazelle, A., Guerra, S., Westerdahl, D., Martinez, D., Bouso, L., Carrasco-Turigas, G., Hoffmann, B., and Nieuwenhuijsen, M. J.: Arterial blood pressure responses to short-term exposure to low and high traffic-related air pollution with and without moderate physical activity, Eur J Prev Cardiol, 22, 548-557, 10.1177/2047487314555602, 2015.

Kubesch, N. J., de Nazelle, A., Westerdahl, D., Martinez, D., Carrasco-Turigas, G., Bouso, L., Guerra, S., and Nieuwenhuijsen, M. J.: Respiratory and inflammatory responses to short-term exposure to traffic-related air pollution with and without moderate physical activity, Occup Environ Med, 72, 284-293, 10.1136/oemed-2014-102106, 2015.

Lanki, T., de Hartog, J. J., Heinrich, J., Hoek, G., Janssen, N. A., Peters, A., Stölzel, M., Timonen, K. L., Vallius, M., Vanninen, E., and Pekkanen, J.: Can we identify sources of fine particles responsible for exercise-induced ischemia on days with elevated air pollution? The ULTRA study, Environ Health Perspect, 114, 655-660, 10.1289/ehp.8578, 2006.

Liu, W.-T., Ma, C.-M., Liu, I. J., Han, B.-C., Chuang, H.-C., and Chuang, K.-J.: Effects of commuting mode on air pollution exposure and cardiovascular health among young adults in Taipei, Taiwan, International journal of hygiene and environmental health, 218, doi:https://dx.doi.org/10.1016/j.ijheh.2015.01.003, 2015.

Liu, L., Urch, B., Nanthakumar, K., Chen, L., Smith-Doiron, M., Brook, J. R., Speck, M., Silverman, F., and Stieb, D. M.: Air Pollution, Physical Activity and Cardiovascular Function of Patients with Implanted Cardioverter Defibrillators: A Randomized Controlled Trial of Indoor Versus Outdoor Activity, Journal of occupational and environmental medicine, doi:https://dx.doi.org/10.1097/JOM.0000000000001795, 2019.

Marmett, B., Carvalho, R. B., Nunes, R. B., and Rhoden, C. R.: Exposure to O3 and NO2 in physically active adults: an evaluation of physiological parameters and health risk assessment, Environmental geochemistry and health, 44, doi:https://dx.doi.org/10.1007/s10653-021-01194-5, 2022.

Matt, F., Cole-Hunter, T., Donaire-Gonzalez, D., Kubesch, N., Martínez, D., Carrasco-Turigas, G., and Nieuwenhuijsen, M.: Acute respiratory response to traffic-related air pollution during physical activity performance, Environ Int, 97, 45-55, 10.1016/j.envint.2016.10.011, 2016.

McCreanor, J., Cullinan, P., Nieuwenhuijsen, M. J., Stewart-Evans, J., Malliarou, E., Jarup, L., Harrington, R., Svartengren, M., Han, I. K., Ohman-Strickland, P., Kian, F. C., and Zhang, J.:

Respiratory effects of exposure to diesel traffic in persons with asthma, New England Journal of Medicine, 357, doi:https://dx.doi.org/10.1056/NEJMoa071535, 2007.

Mills, N. L., Tornqvist, H., Gonzalez, M. C., Vink, E., Robinson, S. D., Soderberg, S., Boon, N. A., Donaldson, K., Sandstrom, T., Blomberg, A., and Newby, D. E.: Ischemic and thrombotic effects of dilute diesel-exhaust inhalation in men with coronary heart disease, The New England journal of medicine, 357, doi:, 2007.

Mitsakou, C., Gowers, A., Exley, K., Milczewska, K., Evangelopoulos, D., Walton, H., 2022. Updated mortality burden estimates attributable to air pollution. Chemical Hazards and Poisons Report. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1083447/CHaPR_AQ_Special_Edition_2206116.pdf: UK Health Security Agency; 2022.

Mudway, I. S., and Kelly, F. J.: An investigation of inhaled ozone dose and the magnitude of airway inflammation in healthy adults, Am J Respir Crit Care Med, 169, 1089-1095, 10.1164/rccm.200309-1325PP, 2004.

Nwokoro, C., Ewin, C., Harrison, C., Ibrahim, M., Dundas, I., Dickson, I., Mushtaq, N., and Grigg, J.: Cycling to work in London and inhaled dose of black carbon, European Respiratory Journal, 40, doi:https://dx.doi.org/10.1183/09031936.00195711, 2012.

Pasqua, L. A., Damasceno, M. V., Cruz, R., Matsuda, M., Martins, M. G., Lima-Silva, A. E., Marquezini, M., Saldiva, P. H. N., and Bertuzzi, R.: Exercising in Air Pollution: The Cleanest versus Dirtiest Cities Challenge, Int J Env Res Pub He, 15, ARTN 1502, 10.3390/ijerph15071502, 2018.

Pekkanen, J., Peters, A., Hoek, G., Tiittanen, P., Brunekreef, B., Hartog, J. d., Heinrich, J., Ibald-Mulli, A., Kreyling, W. G., Lanki, T., Timonen, K. L., and Vanninen, E.: Particulate Air Pollution and Risk of ST-Segment Depression During Repeated Submaximal Exercise Tests Among Subjects With Coronary Heart Disease, Circulation, 106, 933-938, doi:10.1161/01.CIR.0000027561.41736.3C, 2002.

Raza, W., Krachler, B., Forsberg, B., and Sommar, J. N.: Does Physical Activity Modify the Association between Air Pollution and Recurrence of Cardiovascular Disease?, Int J Env Res Pub He, 18, ARTN 2631, 10.3390/ijerph18052631, 2021.

Rundell, K. W., Hoffman, J. R., Caviston, R., Bulbulian, R., and Hollenbach, A. M.: Inhalation of ultrafine and fine particulate matter disrupts systemic vascular function, Inhalation Toxicology, 19, doi:https://dx.doi.org/10.1080/08958370601051727, 2007.

Shrestha, P. M., Humphrey, J. L., Carlton, E. J., Adgate, J. L., Barton, K. E., Root, E. D., and Miller, S. L.: Impact of Outdoor Air Pollution on Indoor Air Quality in Low-Income Homes during Wildfire Seasons, Int J Environ Res Public Health, 16, 10.3390/ijerph16193535, 2019.

Sinharay, R., Gong, J., Barratt, B., Ohman-Strickland, P., Ernst, S., Kelly, F. J., Zhang, J. J., Collins, P., Cullinan, P., and Chung, K. F.: 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 (London, England), 391, doi:https://dx.doi.org/10.1016/S0140-6736%2817%2932643-0, 2018.

Stieb, D., Shutt, R. H., Kauri, L. M., Mason-Renton, S., Chen, L., Szyszkowicz, M., Dobbin, N. A., Rigden, M., Jovic, B., Mulholland, M., Green, M. S., Liu, L., Pelletier, G., Weichenthal, S. A., Dales, R. E., Andrade, J., and Luginaah, I.: Associations between air pollution and cardio-respiratory physiological measures in older adults exercising outdoors, Int J Environ Health Res, 31, 901-914, 10.1080/09603123.2019.1699506, 2021.

Strak, M., Boogaard, H., Meliefste, K., Oldenwening, M., Zuurbier, M., Brunekreef, B., and Hoek, G.: Respiratory health effects of ultrafine and fine particle exposure in cyclists, Occupational and Environmental Medicine, 67, 118, 10.1136/oem.2009.046847, 2010.

Syed, N., Ryu, M. H., Dhillon, S. S., Schaeffer, M. R., Ryerson, C. J., Ramsook, A. H., Leung, J., Carlsten, C., and Guenette, J. A.: Effect of diesel exhaust on exercise endurance and cardiorespiratory responses to exercise in chronic obstructive pulmonary disease and healthy controls-a randomized, placebo controlled, crossover study, American Journal of Respiratory and Critical Care Medicine, 203, doi:https://dx.doi.org/10.1164/ajrccm-conference.2021.203.1_MeetingAbstracts.A1054, 2021.

Tainio, M., de Nazelle, A. J., Götschi, T., Kahlmeier, S., Rojas-Rueda, D., Nieuwenhuijsen, M. J., de Sá, T. H., Kelly, P., and Woodcock, J.: Can air pollution negate the health benefits of cycling and walking?, Preventive Medicine, 87, 233-236, https://doi.org/10.1016/j.ypmed.2016.02.002, 2016.

Tainio, M., Jovanovic Andersen, Z., Nieuwenhuijsen, M. J., Hu, L., de Nazelle, A., An, R., Garcia, L. M. T., Goenka, S., Zapata-Diomedi, B., Bull, F., and Sá, T. H. d.: Air pollution, physical activity and health: A mapping review of the evidence, Environment International, 147, 105954, https://doi.org/10.1016/j.envint.2020.105954, 2021.

Weichenthal, S., Hatzopoulou, M., and Goldberg, M. S.: Exposure to traffic-related air pollution during physical activity and acute changes in blood pressure, autonomic and micro-vascular function in women: A cross-over study, Particle and Fibre Toxicology, 11, doi:https://dx.doi.org/10.1186/s12989-014-0070-4, 2014.

WHO: Global action plan on physical activity 2018–2030: more active people for a healthier world, World Health Organization, Geneva, 2018.

WHO: WHO guidelines on physical activity and sedentary behaviour: at a glance, World Health Organization, Geneva, 2020.

WHO: Review of evidence on health aspects of air pollution: REVIHAAP project: technical report, World Health Organization. Regional Office for Europe, Copenhagen, 2021.

Appendix A

Ovid MEDLINE(R) ALL <1946 to February 13, 2023>

1 Air Pollution/ 38744
2 Air Pollutants/ 56918
3 Particulate Matter/ 27307
4 ultrafine particles.ti,ab,kw. 1943
5 air pollut*.ti,ab,kw. 43557
6 (black carbon or soot).ab,kw,ti. 5598
7 soot/ 2022
8 Nitric Oxide/ 95678
9 Nitrogen Dioxide/ 6364
10 Ozone/ 17315
11 Sulfur Dioxide/ 5864
12 Vehicle Emissions/ 11556
13 ((traffic or vehicle or car or transport*) adj3 (emission* or emitting)).ab,kw,ti. 4764
14 "PM2.5".mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms] 18021
15 smog.ab,kw,ti. 1570
16 smog/ 577
17 (air adj2 quality).ab,kw,ti. 16781
18 particulate matter.ab,kw,ti. 26531
19 "NOx".ab,kw,ti. 13070
20 "NO2".ab,kw,ti. 19996
21 nitrogen dioxide.ab,kw,ti. 6925
22 smoke.ab,kw,ti. 56444
23 smoke/ 9769
24 ozone.ab,kw,ti. 25436
25 "O3".ab,kw,ti. 16254
26 "SO2".ab,kw,ti. 11686
27 (sulfur dioxide or sulphur dioxide).ab,kw,ti. 6530
28 Nitrogen Oxide*.ab,kw,ti. 4795
29 Nitrogen Oxides/ 7379
30 PM10.ab,kw,ti. 8981
31 or/1-30 326078
32 exp Exercise/ 241370
33 (physical adj2 activit*).ti,ab,kw. 145000
34 exp Running/ or (running or runner*1 or Jogger*1 or jogging).ti,ab,kw. 83125
35 walking/ or (walker*1 or walking).ti,ab,kw. 111815
36 High-Intensity Interval Training/ 2018
37 (HIIT or high intensity interval training).ti,ab,kw. 2996
38 exp sports/ 212772
39 sport*.ti,ab,kw. 100093
40 recreation/ 7283
41 ((outdoor or construction) adj3 (work* or labo?r*)).ti,ab,kw. 5291
42 (recreation* adj3 activit*).ab,kw,ti. 5134
43 or/32-42 599210
44 exp Cardiovascular Diseases/ 2682882
45 (coronary heart disease or CHD or coronary artery disease or CAD).ti,ab,kw. 183616

46 (chronic heart failure or CHF).ti,ab,kw. 28288
47 exp Heart Failure/ 144095
48 exp Asthma/ or asthma.ti,ab,kw. 195156
49 (chronic obstructive pulmonary disease or COPD).ti,ab,kw. 77155
50 (chronic and obstructive and (airway or respiratory or lung) and disease).ti,ab,kw. 36140
51 Pulmonary Disease, Chronic Obstructive/ 49068
52 (Interstitial lung disease or ILD).ti,ab,kw. 14488
53 exp Lung Diseases, Interstitial/ 83674
54 (cardiovascular disease* or CVD).ti,ab,kw. 235027
55 Metabolic Diseases/ or metabolic disease*.ti,ab,kw. 38932
56 Diabetes Mellitus, Type 2/ 166265
57 (diabet* adj2 ("type 2" or "type II")).ti,ab,kw. 180389
58 exp Obesity/ or obes*.ti,ab,kw. 426938
59 exp Neoplasms/ 3793612
60 (cancer* or tumo?r* or neoplas*).ab,kw,ti. 3456866
61 Intra-Abdominal Fat/ 6723
62 visceral fat.ab,kw,ti. 9100
63 waist circumference.ab,kw,ti. 33288
64 Waist Circumference/ 12660
65 Adipose Tissue/ or Adiposity/ 100540
66 overweight/ or (overweight or "over weight").ti,ab,kw. 90958
67 "adipos*".ab,kw,ti. 130400
68 exp Chronic Disease/ 606958
69 ((chronic or long-term or "long term") adj2 (illness* or condition* or disease*)).ti,ab,kw. 311293
70 or/44-69 8744700
71 31 and 43 and 70 2063

Embase <1974 to 2023 February 13>

1 air pollution/ 70413
2 air pollutant/ 37855
3 particulate matter/ 49373
4 ultrafine particles.ti,ab,kw. 2952
5 ultrafine particulate matter/ 526
6 air pollut*.ti,ab,kw. 54927
7 (black carbon or soot).ab,kw,ti. 8809
8 black carbon/ 3601
9 soot/ 3943
10 nitric oxide/ 178309
11 nitrogen dioxide/ 17271
12 ozone/ 32899
13 sulfur dioxide/ 16725
14 exhaust gas/ 21000
15 ((traffic or vehicle or car or transport*) adj3 (emission* or emitting)).ab,kw,ti. 6895
16 "PM2.5".mp. 24396
17 "particulate matter 2.5"/ 5984
18 smog.ab,kw,ti. 2525

19 smog/ 1108
20 (air adj2 quality).ab,kw,ti. 23610
21 air quality/ 21265
22 particulate matter.ab,kw,ti. 35006
23 "NOx".ab,kw,ti. 20114
24 "NO2".ab,kw,ti. 27941
25 nitrogen dioxide.ab,kw,ti. 8612
26 smoke/ 17006
27 smoke.ab,kw,ti. 75884
28 ozone.ab,kw,ti. 34048
29 "O3".ab,kw,ti. 18884
30 "SO2".ab,kw,ti. 18527
31 (sulfur dioxide or sulphur dioxide).ab,kw,ti. 9089
32 Nitrogen Oxide*.ab,kw,ti. 6935
33 nitrogen oxide/ 12391
34 PM10.ab,kw,ti. 13770
35 "particulate matter 1.0"/ 2494
36 or/1-35 487365
37 exp exercise/ 414411
38 (physical adj2 activit*).ti,ab,kw. 195702
39 exp Running/ or (running or runner*1 or Jogger*1 or jogging).ti,ab,kw. 103780
40 walking/ or (walker*1 or walking).ti,ab,kw. 155525
41 high intensity interval training/ 4141
42 (HIIT or high intensity interval training).ti,ab,kw. 3799
43 exp sport/ 204612
44 sport*.ti,ab,kw. 129407
45 recreation/ 20552
46 (recreation* adj3 activit*).ab,kw,ti. 6490
47 ((outdoor or construction) adj3 (work* or labo?r*)).ti,ab,kw. 6627
48 or/37-47 935235
49 exp cardiovascular disease/ 4827020
50 (coronary heart disease or CHD or coronary artery disease or CAD).ti,ab,kw. 287821
51 (chronic heart failure or CHF).ti,ab,kw. 50889
52 exp heart failure/ 611630
53 exp Asthma/ or asthma.ti,ab,kw. 330300
54 (chronic obstructive pulmonary disease or COPD).ti,ab,kw. 136298
55 (chronic and obstructive and (airway or respiratory or lung) and disease).ti,ab,kw. 54679
56 chronic obstructive lung disease/ 165971
57 (Interstitial lung disease or ILD).ti,ab,kw. 28802
58 exp interstitial lung disease/ 101444
59 (cardiovascular disease* or CVD).ti,ab,kw. 343306
60 Metabolic disorder/ or metabolic disease*.ti,ab,kw. 101155
61 (diabet* adj2 ("type 2" or "type II")).ti,ab,kw. 280203
62 non insulin dependent diabetes mellitus/ 320082
63 exp Obesity/ or obes*.ti,ab,kw. 753302
64 exp malignant neoplasm/ 3823064
65 (cancer* or tumo?r* or neoplas*).ab,kw,ti. 4664971
66 intraabdominal fat/ or intra-abdominal fat/ 20110
67 visceral fat.ab,kw,ti. 14825
68 waist circumference.ab,kw,ti. 53012

69 waist circumference/ 68083
70 adipose tissue/ 88293
71 "adipos*".ab,kw,ti. 175720
72 (overweight or "over weight").ti,ab,kw. 130242
73 exp chronic disease/ 204926
74 ((chronic or long-term or "long term") adj2 (illness* or condition* or disease*)).ti,ab,kw. 462290
75 or/49-74 11562201
76 36 and 48 and 75 6267