Air Pollution Exposure in Different Transport Modes

In this Briefing Note, we summarise recent scientific evidence on air pollution exposure experienced by people travelling by different surface transport modes: including road, rail, and active travel (walking and cycling). We also consider which factors influence pollutant exposure within each mode and provide recommendations to mitigate against adverse health impacts.

Overview

- Individuals are exposed to high concentrations of air pollutants when travelling in, or close to, motorised vehicles.
- Many factors influence the duration and intensity of air pollution exposure, including: route choice, ventilation settings, in-vehicle passenger position, proximity to vehicles and time of day.
- The benefits of physical activity from walking and cycling typically outweigh any disbenefits due to increased air pollution exposure.

Background

Air pollution is the greatest environmental risk to human health.[1] In the UK, air pollution exposure is responsible for 29,000 – 43,000 premature deaths annually.[2] The transport sector remains a large source of air pollution globally[3,4], emitting harmful air pollutants such as nitrogen dioxide (NO_2) and fine particulate matter ($PM_{2.5}$) from both exhaust[5] and non-exhaust[6,7] sources. The sector also contributes substantially to greenhouse gas emissions[8], and other health burdens such as noise pollution[9] and road accidents.[10] In the UK, roadsides are associated with high concentrations of air pollutants (notably NO_2) and are a focus of policy action.[11] People working, living or travelling besides roads are thereby exposed to harmful air pollutant concentrations, often exceeding WHO 2021 Global Air Quality Guidelines.[12] Short and long-term exposure to traffic-related air pollutants (TRAPs) is associated with adverse health effects including risk of asthma, low birth weight, lung cancer and all-cause mortality.[13] Those most affected by TRAP are disadvantaged communities who typically live in more polluted areas,[14] and have higher incidence of pre-existing health conditions rendering them more vulnerable to harmful air quality impacts.[15] However, transport of people, goods and services by surface transport mode has an integral societal and economic role. In 2019, people in England spent on average around 370 hours travelling[16] for a variety of reasons including leisure (26% of trips), shopping (19% of trips), commuting (15% of trips), education (13% of trips) and other purposes including recreational walking (6% of trips). Despite most people spending only a relatively short amount of time each day travelling (~6%), pollutant exposure in transport microenvironments can account for around 30% of daily cumulative exposure.[17] Therefore, reducing transport-related air pollution can provide important health benefits for the majority of the general population.[18] The intensity and duration of exposure, however, is known to vary between different transport modes, and understanding these differences, who they affect, and actions which can be taken to protect citizens, is a key focus of ongoing research.[19]

Comparison of air pollutant exposures

The question of how air pollution exposure varies according to travel mode has been the focus of several recent reviews.[20,21,22] This briefing note builds upon a systematic review by Mitsakou et al. (2021): '*Assessing the exposure to air pollution during transport in urban areas – Evidence review*'.[17] This review critically assessed 40 papers, published between 2016-2020, and focussed on comparisons between journey-average concentrations encountered in active travel and motorised transport modes: bus (29 comparisons), rail and light rail (12 comparisons), cars with windows open (14 comparisons) and cars with windows closed (34 comparisons).

Overall, measured concentrations of air pollutants were greater in motorised transport compared to active travel modes. In 38% of comparisons, car users were exposed to higher concentrations than those using active travel modes (walking and cycling). However, important differences were also observed between car users, depending on whether they travelled with the windows open or closed. People travelling in cars with windows open experienced higher concentrations than those in active travel modes in 64% of studied journeys. However when travelling with windows closed, car users experienced higher concentrations than active travel modes in only 26% of studied journeys. These findings were consistent with previous reviews suggesting closing car windows may limit exposure to ambient air pollution compared to active travel modes in the same environment. In terms of public transport, bus users were mostly exposed to similar concentrations to those experienced by cyclists, but this varied with bus characteristics (e.g., route travelled, location and frequency of stops - see later).

Pollutant concentration differences between transport modes can also differ according to the pollutant of interest. For example, one recent study conducted in Leicester observed higher NO_2 concentrations in cars compared to cycling (41-48% higher) and walking (10-45% higher) but 19-31% lower PM2.5 concentrations in cars compared to active travel.[23] Such caveats highlight the complexity of factors influencing individual exposure, and the value of high-quality primary research and evidence reviews to better understand what conclusions may be drawn to inform policy decisions.

Case study: Exposure during active travel

The Mitsakou et al. (2021) review focused solely on the pollutant concentrations in different transport environments. Exposure of individual travellers also depends on how long they spend in those environments, and how frequently/deeply they are breathing whilst they do so. While engaging in active travel, higher ventilation rates associated with physical activity may result in greater respiratory uptake and deposition of air pollutants.[24] Allowing for these factors, active travellers may experience greater exposure than motorised transport users.[25] Importantly, however, active travel also provides significant, direct health benefits through physical activity,[26] and the current evidence suggests these health benefits outweigh the disbenefits of air pollution exposure.[27] Active travel also provides important mental health benefits[28] and offers a sustainable, zero-emission transport alternative that can help mitigate climate change[29] and improve urban air quality.[26]

Factors affecting pollutant exposure

Route choice

Air pollutant concentrations are highest at 'source'; i.e., the points of friction between vehicles' brakes and wheels, and wheels and roads, as well as their exhaust pipes. Route choice can therefore significantly affect what concentrations of pollutants individuals are exposed to. Choosing high-traffic routes can result in exposure to 2.6-3.4 times higher air pollutant concentrations when cycling, and 1.5-7 times higher concentrations when walking, compared to traffic-free routes. The closer a person is to the pollutant source, the more the distance from source matters: cyclists travelling on a carriageway may be exposed to 1.3–4.4 times higher concentrations than those using cycle lanes further away from motorised traffic. Route choice also affects exposure in motorised vehicles. One study found that car and bus users experienced 20% and 70% higher NO_2 concentrations, respectively, on urban routes compared to sub-urban routes.[30]

Ventilation settings

As enclosed environments, vehicles have the potential to accumulate pollutants, either from the ingress of outdoor air pollutants or from internal sources, such as volatile organic compounds (VOCs) degassing from interior fittings. Ventilation settings can therefore influence an individual's exposure – however the variety of different settings limits definitive conclusions. In general, closing car windows and operating ventilation in recirculation mode is thought to reduce in-vehicle particulate concentrations.[17] Particulate concentrations in cars with windows open were generally 1.2-5.5 times higher than in cars with windows closed. The concentrations in cars with windows closed, but without recirculation, were 1.3–6.9 times higher than in cars with windows closed *and* recirculation switched on. Some studies have however highlighted that prolonged recirculation could lead to the accumulation of exhaled carbon dioxide (CO_2), which can result in concentration difficulties or fatigue.[31] Optimal ventilation settings can reduce internal exposure to ambient air pollution (by 49% for $PM_{2.5}$ and 34% for NO_2).[32]

In-vehicle position

Air pollution concentrations in vehicles can also differ by location *within* the vehicle, as well as by the location of the vehicle. Studies have shown that passengers on buses and trains experience different pollutant exposures depending on where they are seated. One study indicates the middle of the bus is associated with more frequent black carbon concentration peaks, due to the opening of middle doors.[33] In trains, the highest concentrations are observed in carriages located closest to the locomotive engine.[34,35]

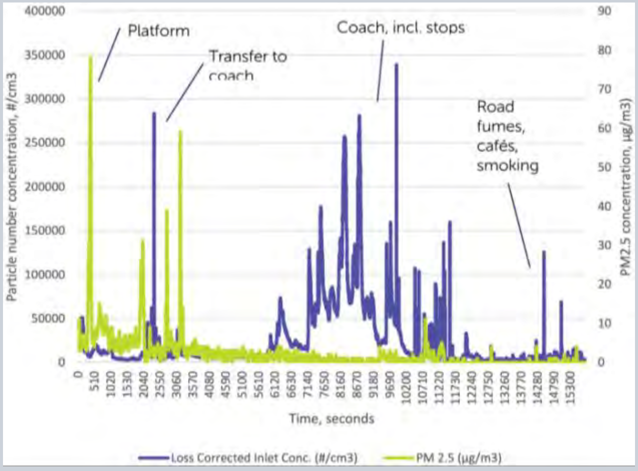
Time of day

Close proximity to high volumes of motorised traffic is associated with higher concentrations of air pollutants. However, traffic volumes are not static with time of day. Generally, commuting 'rush-hour' periods are associated with higher pollutant concentrations, particularly in the evening (up to 1.9 times higher than the morning)[17]; Traffic volume reduction - as observed during COVID-19 lockdown - can reduce peak NO and NO_2 concentrations at roadside during rush hour periods.[36]

Case study: Exposure for a London-Oxford commuting trip

In a recent pilot study, Emissions Analytics in association with TRANSITION Clean Air Network assessed pollutant exposure for typical commuting trips from London Paddington station to Oxford City Centre via nine different transport modes (including electric and diesel variants).[37] The diesel coach had the highest concentrations of VOCs and ultrafine particles, and poor air freshness, with exposure compounded by relatively long travel times. Rail journeys were associated with the highest short-duration spikes In particulate concentrations, usually occurring while waiting at train platforms, and boarding and alighting trains. Private cars typically afforded better protection than buses and trains, through better filtration in ventilation systems.

The electric car showed similar in-car particulate concentrations to the diesel car but significantly higher VOC concentrations (likely attributable to its newer interior). Active travel generally saw the lowest average concentrations of particulates and VOCs – however they were still affected by high urban spikes corresponding to roadside 'hotspots' or passing a cigarette smoker (see example graph below).



Recommendations

1. The best way to reduce exposure to air pollution is to reduce air pollutant emissions. Therefore concerted effort to reduce emissions from motorised vehicles, as well as dependency and usage of them (in terms of total miles travelled), is required.
2. Modal shift towards public transport and active travel is key to reducing both the number of motorised-vehicle movements, and road congestion that increases emissions from those movements. The best possible public transport provision is necessary, employing cleaner vehicle technologies, and attractive, safe and well-connected active travel routes.
3. To reduce pollutant exposure in public transport settings, the ventilation of buses, coaches and train carriages should be optimised according to the relationship between in-cabin and outdoor air quality: i.e., increased (decreased) when in-cabin air quality is worse (better) than outdoor air quality—whilst, at all times, ensuring sufficient air freshness to avoid ill-effects for the driver and passengers. Passengers particularly vulnerable to air pollution are best seated far from doors.
4. To reduce exposure in active travel settings, pedestrian and cycleways should, wherever possible, be routed away from motorised vehicles—whilst ensuring the routes are safe and attractive to use for all.
5. To reduce exposure in personal vehicles, car drivers should be alerted to the benefits of keeping their windows closed and, whilst ensuring sufficient air freshness to avoid fatigue or loss of concentration, the recirculation of air within the car. They may also have the option of driving when there is less traffic and at times of day when air quality is better.
6. Employers can help their employees reduce exposure by offering home-working options and flexible start times, reducing their need to travel and/or giving them more choice as to how and when they travel. Such practices can also reduce the intensity of traffic in 'rush hours' and thereby reduce congestion.

Future research

Further research is needed in the following areas to inform additional policy actions:

- Relative health impacts of short-duration exposure to very high pollutant concentrations, compared to longer exposure to lower concentrations.
- Optimal design of public transport vehicles, especially the ventilation and/or recirculation of air within vehicles, for minimum passenger and driver exposure.
- Impacts of route choice on in-vehicle exposure as a result of differences in congestion and outdoor air quality, and also

vehicle operation and driver behaviour (e.g., speed, cornering, accelerating and braking).

- Standardised methods for measuring in-vehicle exposures and assessing the real-world efficacy of mitigations.

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