



The Driver Diesel Exposure Mitigation Study (DEMIST)

Summary report 2020

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MRC
Centre for Environment & Health



Imperial College
London



What's the problem?

Exposure to traffic-related air pollutants in ambient air is associated with negative impacts on the population's health. In particular, diesel exhaust exposures have been associated with increased hospitalisations and premature deaths, as well as being linked to a range of cardiovascular and respiratory health problems. In 2012, the International Agency for Research on Cancer classified these exposures as carcinogenic to humans. Studies to date have primarily focused on the exposure to diesel fumes of those who live close to busy roads, but they have failed to focus adequately on vehicle drivers, who constitute a high exposure group. Professional drivers, particularly those working in congested urban locations, are likely to be disproportionately affected by diesel exhaust exposures during their working day.

Existing research on in-vehicle driver exposures has predominantly focused on short commutes to and from a fixed place of work in morning and evening rush hours. The results of these studies show a large variation in traffic-related air pollution experienced by drivers while commuting. Occupational exposure studies, meanwhile, have largely focused on long-haul professional drivers, but minimal research has been conducted on professional drivers' exposures when working in urban areas. In many countries, employers have a legal duty to consider the risk of cancer to their employees from work activities and to act to reduce this risk if there are activities of concern. This suggests a need for specific studies focusing on urban professional drivers in order to better understand their unique working environment, and also to highlight what interventions might reduce exposure to these pollutants.

We therefore commissioned Dr Ian Mudway, Dr Benjamin Barratt and Shanon Lim at Medical Research Council Centre for Environment and Health, Environmental Research Group, King's College London to conduct work in this area.

* Shanon Lim, Dr. Benjamin Barratt and Dr. Ian Mudway have been located at the Medical Research Council Centre for Environment & Health at Imperial College London since July 2020.

Aims

The aims of this project were to quantify the exposure of urban professional drivers to diesel exhaust, to provide a framework for evaluating their risk, and to allow for the formulation of risk reduction strategies.

Objectives

In addressing these questions the research sought to:

1. to conduct a baseline study to assess high time resolved exposures to diesel exhaust for professional drivers in both working and home environments

2. to identify the key determinants of drivers' diesel exhaust exposure through analysis of driver behaviours
3. to trial and evaluate intervention methods aimed at reducing exposures on a subset of professional drivers.

What did our researchers do?

Recruitment: The study was conducted in two stages:

1. A baseline study measured 141 drivers' exposures to diesel exhaust over four working days and across various professional driving sectors in London. Measurements were analysed to characterise and provide insight into the determinants of driver exposure.
2. An intervention study of 42 drivers was completed to assess the effectiveness of portable in-cabin filters in reducing driver exposure.

Participants were recruited in groups of between five and ten drivers by approaching a gatekeeper at each of their organisations. The professional driving occupations targeted were taxi drivers, couriers, waste removal, heavy freight, bus drivers, utility services, passenger transport and emergency services.

Measuring diesel exhaust: Diesel exhaust is difficult to measure in practice as it consists of a mixture of gases, volatile organic compounds and primary combustion particles. The pollutant 'black carbon' (BC) was therefore measured as a proxy. It is derived predominantly from diesel engines in the urban environment and numerous health studies have demonstrated that daily fluctuations in the concentration of BC in ambient air are associated with adverse health effects in the population. BC exposure was measured by providing each driver with a portable microAeth (MA) 300/350, which has an in-built GPS. Prior to deployment, all devices were co-located with a reference monitor at the London Marylebone Road reference site to ensure accuracy. Results were audited by visualising data to observe general trends and to flag any unusual data such as wildly fluctuating concentrations, or constantly negative values. In total, 9 per cent of data collected were not considered for further analysis.

Characterising driver exposure: Each participant's data set comprised of one-minute resolution BC exposures, with date and time, GPS coordinates, speed, and bearing. Each one-minute point was labelled to show if the participant was at work or not, what shift they were working, the predominant ventilation setting used during their shift, the predominant window position used, the vehicle type, and whether or not the participant was moving based on GPS stratification. Activities were labelled as follows: 'At work driving' (during work hours and moving); 'At work not driving'

(during work hours and stopped); 'Commuting' (outside of work hours and moving); and 'At home' (outside of work hours and stopped).

Analysing determinants and interventions: Determinants of high driver exposure to diesel exhaust were determined using a mixed-effects model. Determinants included in the analysis were: ventilation settings; window position; generic vehicle type (i.e. van, truck, taxi, etc.); vehicle speed; time of day; weekday or weekend; season; location; sector; fuel type; make and model of vehicle; whether or not the participant was a smoker; meteorological parameters; and background BC concentrations.

What did our researchers find out?

Characterising professional drivers' exposures: In total, 11,492 hours of professional drivers' exposure data were analysed in the baseline monitoring campaign, corresponding to more than 600,000 data points. The average overall exposure for participants was $2.0 \pm 1.4 \mu\text{g}/\text{m}^3$. 'At work driving' exposures ($4.2 \pm 4.7 \mu\text{g}/\text{m}^3$) were 1.9 times higher compared to 'at work not driving' exposures ($2.2 \pm 2.2 \mu\text{g}/\text{m}^3$) ($p < 0.05$) and 3.8 times higher than 'at home' exposures ($1.1 \pm 0.7 \mu\text{g}/\text{m}^3$) ($p < 0.05$). The standard deviations were often higher than mean exposures, indicating a large variability and, at times, very high levels of BC exposures experienced by participants. On average, 18.6 per cent of time was spent by the participants 'at work driving', but this contributed 36.1 per cent of total BC exposure. Altogether, 54.4 per cent of time was spent 'at home' but this only contributed 31.8 per cent of total BC exposure. Average 'commuting' exposures were comparatively high ($3.6 \pm 2.5 \mu\text{g}/\text{m}^3$) but with only 4.0 per cent of time spent in this activity, it only contributed 7.9 per cent of the total exposure. Average 'at work not driving' proportions were relatively similar for BC exposure (24.2 per cent) and time spent (23 per cent), indicating comparatively lower exposures experienced during this activity compared to 'at work driving' (Figure 1).

These results highlight how more than 60 per cent of BC exposures for these participants could be attributed to work activities, despite spending only 42 per cent of their time at work. This emphasises how professional drivers are disproportionately affected by exposure to diesel exhaust compared to other occupations, due to the significant proportion of time they spend driving.

There was a wide range of exposures experienced for individual participants, both within and between different activities, highlighting the complexity of characterising exposures within this mobile population. The occupational sectors with the highest exposures while driving were taxi drivers ($6.6 \mu\text{g}/\text{m}^3$), couriers ($5.5 \mu\text{g}/\text{m}^3$) and waste removal drivers ($4.3 \mu\text{g}/\text{m}^3$), possibly reflecting the fact that these individuals work predominantly within congested, highly polluted areas in central London.

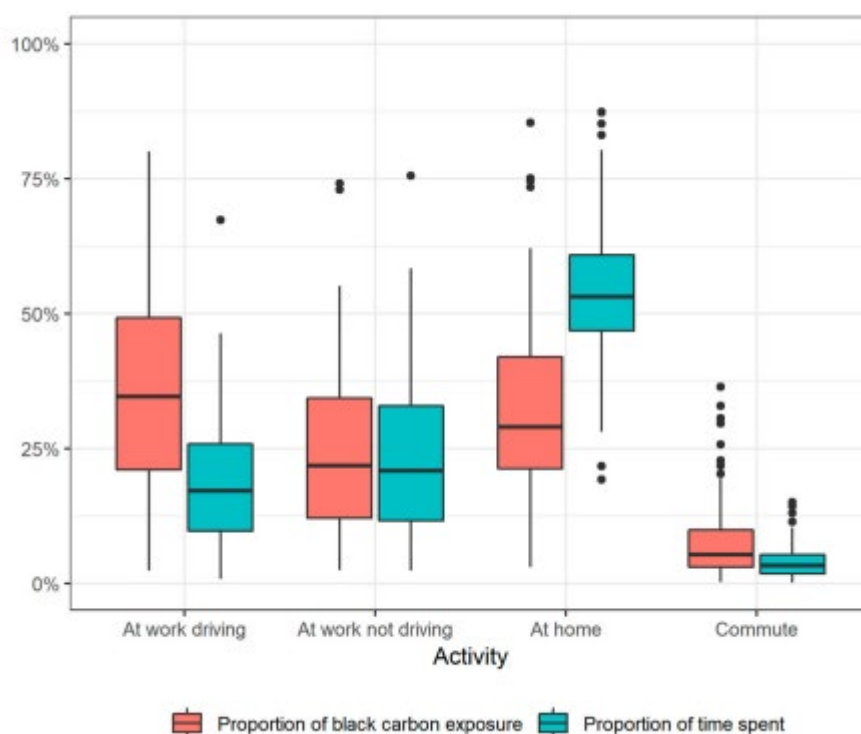


Figure 1: Box plot of the proportion of black carbon exposure and the proportion of time spent in each activity for participants.

Exposure spikes while driving: Spatial and temporal analysis of ‘at work driving’ exposures identified the occurrence of exposure spikes, which at times were above 100 $\mu\text{g}/\text{m}^3$ and appeared to remain trapped within the vehicle cabin for long periods. Increases in exposure while driving were rapid and remained entrapped within the vehicle cabin for between ten minutes and an hour, before returning to pre-spike levels (**Figure 2**).

These spikes often occurred in congested traffic within Central London, in areas where vehicles congregate, such as in car parks or depots, as well as at locations where dispersion is poor, such as in tunnels and street canyons. However, the fact that pollutants are ‘transported’ while driving may partially obscure the determinants of high exposure, particularly as the location of the exposure can be recorded many minutes after the cause of the increase.

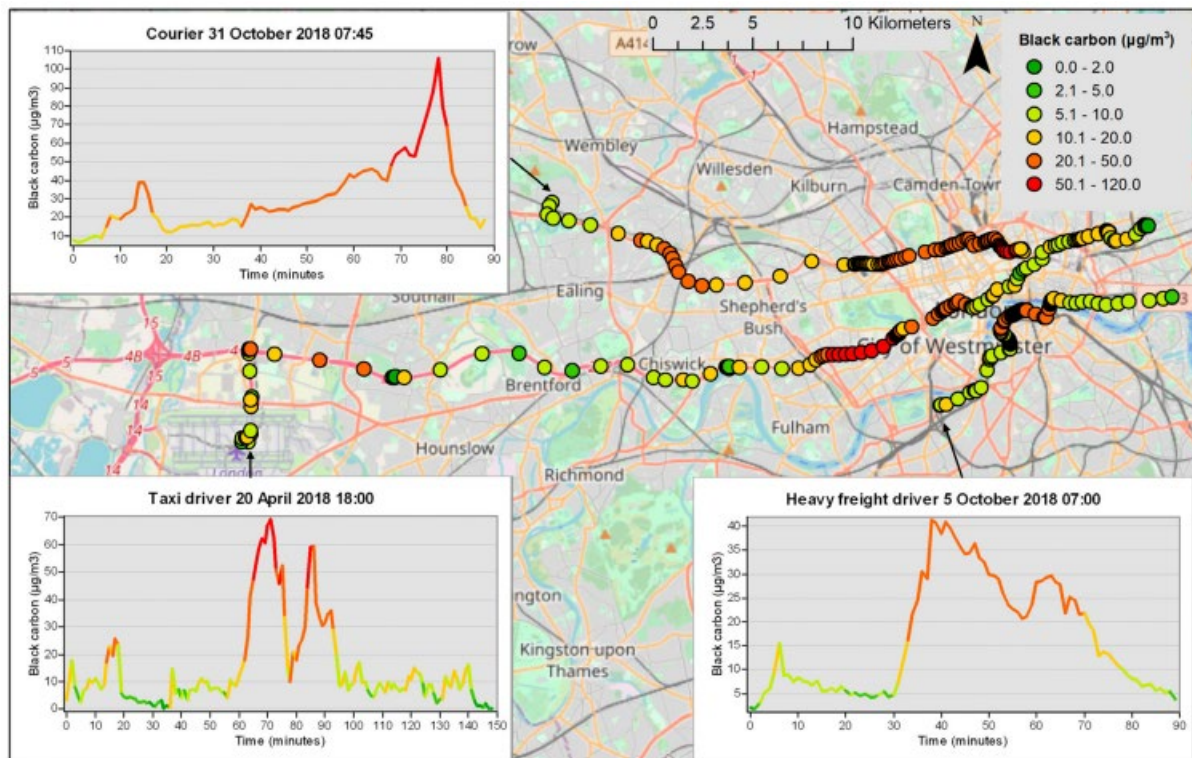


Figure 2: Examples of exposure spikes from a selection of participants while driving from west to east across London (clockwise from top left) from courier, heavy freight and taxi sectors. Arrows point to starting position of each graph and titles indicate starting time of each event. Each dot represents one-minute of exposure.

Determinants of driver exposure and potential interventions: The mixed effects model showed that driving with windows open rather than closed resulted in a $0.44 \mu\text{g}/\text{m}^3$ increase in driver exposure, while there was a $0.60 \mu\text{g}/\text{m}^3$ increase during evening peak times when compared to daytime exposures. A $1.35 \mu\text{g}/\text{m}^3$ decrease in exposure was found when driving at weekends compared with weekdays. Other determinants such as driver location, wind speed, vehicle speed and background BC concentrations were also significant determinants of driver exposure, although they were less influential than the factors above. Recirculate ventilation settings within vehicles also reduced exposure slightly compared with other ventilation modes (when windows were closed). The type of vehicle was also found to affect driver exposure. While further work is needed to specifically evaluate the cause of this difference, it is likely that vehicles with airtight cabins can significantly reduce the infiltration of ambient pollutants into the vehicle cabin and thus reduce driver exposures.

The results on the effectiveness of in-cabin filters to reduce drivers' exposure to BC were inconclusive and so further research in this area is required. There appeared to

be situations where, despite using the devices, the drivers' exposures remained very high, as was observed with two participants. When these high exposure participants were removed from analysis, results revealed a statistically significant reduction for 'at work driving' exposures with the mixed effects model, indicating a decrease of 0.40 µg/m³ for a shift.

What does the research mean?

This research had several significant results:

1. The study is one of the first to comprehensively demonstrate that professional drivers are disproportionately affected by diesel exhaust exposures within urban areas
2. We identified the occurrence of 'exposure spikes', which significantly increased driver exposure for periods of up to an hour. The diesel exhaust exposure occurring during these 'spike' periods was consistent with levels that have previously been shown to induce inflammation in the lungs of volunteers in experimental exposure studies
3. We identified pertinent determinants associated with elevated exposure to professional drivers
4. We performed initial trials of practical interventions that fleet operators could implement to reduce drivers' exposure to diesel exhaust.

The research has several implications for occupational health and safety. The most effective way to reduce drivers' exposures to diesel exhaust is to change to zero tailpipe emission vehicles with airtight cabins. This will not only reduce drivers' exposures but also reduce ambient concentrations, which will provide health benefits for the general population. Effective policy and regulation would also assist with reducing professional drivers' exposures. A wider and more stringent application of policies aimed at reducing congestion and vehicle emissions would be beneficial. However, we acknowledge there is both a significant cost and a lack of available technology to do this easily.

The following low-cost changes are therefore recommended as intermediate steps to reduce diesel exposures to professional drivers.

- The single simplest change drivers can make to reduce their exposure is to always drive with their windows closed.
- Drivers should use the recirculate ventilation setting with vehicle windows closed. However, this setting should only be used for short periods in high pollution areas, due to the risk of accumulated carbon dioxide levels from respiration caused when using this setting.

- Route choice should be carefully considered to avoid areas of high congestion. Avoiding tunnels will also assist in reducing drivers' exposure.
- Reducing the frequency of driving during the evening peak period (4 pm to 7 pm) will decrease drivers' exposures
- Moving shifts from weekdays to weekends will also reduce drivers' exposures
 - If there are jobs which are likely to result in significantly higher exposures, consideration should be made to rotate drivers to avoid any single worker experiencing significantly higher levels of exposure compared to others
- In-cabin filters in certain circumstances may reduce drivers' exposures

Employers should conduct training and provide information on diesel exhaust exposure. This should be included in induction and refresher training courses so that the impact of diesel exhaust exposure can be minimised.

Don't forget...

While this research produced several important findings, we acknowledge that there were some limitations. We had difficulty recruiting some important professional driving sectors and therefore could have missed some pertinent sector-specific interventions. Reasons given by sectors for not participating in the study were an organisational policy to not take part in research studies, or the perception by the company that there was a commercial risk. While we monitored a wide range of sectors, there also appeared to be sector specific characteristics that caused variation in drivers' exposures that are still not well understood.

The introduction of multiple sectors in several locations may have diluted the strength of suggested interventions. Several variables such as window position, ventilation settings and use of in-cabin filtration devices relied on participants self-reporting and compliance could not be guaranteed. However, due to the very large amount of data recorded, it is likely that incorrect reporting would not have materially affected the results of this study.

While the recommendations in this study identified changes the employer or driver could make, effective policy and regulation would also assist with reducing professional drivers' exposures. A wider and more stringent application of policies to reduce congestion and vehicle emissions would be beneficial in also reducing drivers' exposures.

Our summary gives you the major findings of the independent project report by Medical Research Council Centre for Environment and Health, Environmental Research Group, King's College London. If you want to read about the study in more depth, you can download the full report at [iosh.com/research](https://www.iosh.com/research).

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