Environmental
Research Group

The Breathe London Wearables Study

Engaging primary school children to monitor air pollution in London

King's College London Environmental Research Group

Prepared for the Greater London Authority

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Summary

Exposure to air pollution is a public health concern accountable for wide ranging health problems and tens of thousands of premature deaths each year in the UK. Children are particularly vulnerable to the harmful effects of air pollution. In order to understand how children are exposed to this risk, and where and when the risks are highest, during spring 2019, five London primary schools took part in the Breathe London Wearables study. The aim was to characterise London school children's exposure to air pollution and present this information in a way that the school community could understand, relate and act upon. The five participating schools were part of the 2017 Mayor's School Air Quality Audit Programme, carried out in 50 primary schools located in the most polluted areas of London.

More than 250 children across the five schools were given wearable sensors to carry to and from school for a period of five school days. Throughout this project, the participating children had access to air quality educational lessons delivered by King's College London's air quality scientists and Dyson engineers. During this study, children became 'scientists' too by helping measure air pollution using special backpacks with state-of-the-art air quality sensors inside. This study actively engaged the children in scientific investigation, improving literacy and nurturing their curiosity in science, the environment and their health.

Thanks to our enthusiastic and dedicated young air quality scientists, we were able to gather 490 million measurements. This unique data set gave us the opportunity to compare the different routes and modes of transport used by the children and adults, allowing us to quantify different exposure levels.

The results from this study showed that on average, across all participating schools, the children were exposed to higher levels of air pollution when travelling to and from school, particularly during the morning journey compared to being at school. This study also identified that during the monitoring period, across all schools, the children that walked to and from school through busy main roads were exposed to higher levels of air pollution than those that chose to travel through back streets. Walking, scooting or cycling to school is the healthiest and least polluting choice.

In general, children across all participating schools reported that taking part in this study had boosted their level of air pollution awareness and hence, their understanding of the issue. Through this understanding, children had the opportunity to analyse their own situations (e.g. places and times where they were most likely to be exposed to air pollution) and to propose solutions to reduce exposure to harmful pollutants and or reduce their own contribution to air pollution

CONTENTS

1| INTRODUCTION

Exposure to air pollution is a public health concern accountable for wide ranging health problems and tens of thousands of premature deaths each year in the UK[1]. Children are particularly vulnerable to the harmful effects of air pollution due to their immature and developing immune system and lungs, low body weight and relatively high inhalation rate[2,3]. Air pollution can inhibit children's lung development, and as a result, increase their vulnerability to chronic diseases and respiratory exacerbations[4].

A report, commissioned by the FIA Foundation in 2017, revealed that one in five of London's state primary and secondary schools were in areas with poor air quality in 2013[5]. The single biggest source of air pollution in London is road transport.

In order to tackle the issue and implement effective mitigation strategies, it is important that we understand how children are exposed to this risk, and where and when the risks are highest.

The aim of this study was to characterise London school children's exposure to air pollution and present this information in a way that the school community can understand, relate to and act upon.

Air pollution monitoring is normally carried out by experts using expensive and complex equipment housed in fixed enclosures. However, advances in wearable air pollution sensor technology are creating new opportunities to monitor the quality of air that individuals breathe as they go about their daily lives[6]. This study made use of this new technology to engage with primary school children to monitor air quality across London.

During spring 2019, more than 250 children in five London primary schools were given the opportunity to be an active part of the research process, gathering information about their own exposure to air pollution on their way to and from school and while at school. During this study, and with the help of all of our young "air quality scientists", we were able to monitor nitrogen dioxide (NO_2) and fine particulate matter ($PM_{2.5}$) concentrations during 2,000 journeys, gathering 490 million measurements, making this study the largest of its kind.

Figure 1. The Mayor of London Sadiq Khan launching The Breathe London Wearables Study.

[1]Holgate, S., et al., (2016) Every breath we take: The lifelong impact of air pollution, *Report of a working party*. Royal College of Physicians.
[2] Gehring, U., et al., (2013) Air pollution exposure and lung function in children: the ESCAPE project. *Environmental Health Perspectives.*
[3]Kim, J. J. (2004) Ambient air pollution: health hazards to children. *Pediatrics.*
[4]World Health Organization (2005). Effects of air pollution on children's health and development: A review of the evidence.
[5] Brook, R., et al., (2017) London's Polluted Schools: The social context. In: AETHER (ed.). London: FIA Foundation.
[6] Snyder, E. G., et al., (2013) The Changing Paradigm of Air Pollution Monitoring. *Environmental Science & Technology.*

In addition to these valuable measurements, the study actively engaged the children in scientific investigation, improving literacy and nurturing their curiosity in science, the environment and their health.

Figure 2. Children completing the surveys during the study

To assess the children's and parents' views on air pollution and their involvement in the study, we invited all participating children and their parents to complete a survey before and after the monitoring took place (Figure 2). Upon completion of the study, we also conducted focus groups with the children and their parents, and interviews with some of the teachers involved.

"My role in the project was to be a scientist and discover different types of pollution to help to see how much pollution is there and the difference in the different roads" ***(Child, ME - year 3)***

2| PARTICIPATING SCHOOLS AND SURROUNDING ENVIRONMENT

The five participating schools were part of the 2017 Mayor's School Air Quality Audit Programme, carried out in 50 primary schools located in the most polluted areas of London[7].

Each school had its own unique characteristics and surrounding road layout.

East Sheen (ES) Primary School is in South West London within the Borough of Richmond upon Thames. All children who travel to school on foot currently have to walk along the very busy and heavily trafficked Upper Richmond Road West (South Circular Road) (Figure 3a) to access the school grounds.

Haimo Primary (HA) School is in South East London within the Borough of Greenwich. The school is situated on Haimo Road, which is a narrow two-way local street (Figure 3b). Haimo Road connects with the heavily trafficked dual carriageway South Circular Road about 40 metres to the west of the school. Around 200m from the school, to the north, is the A2, another heavily trafficked dual carriageway.

Lordship Lane (LL) Primary School is in North London within the Borough of Haringey. The school has three entrances. Two of the entrances are on Ellenborough Road, a 20 mph road and a cul-de-sac. The third is on Grenville Road.

Melcombe (ME) Primary School is in West London within the Borough of Hammersmith and Fulham. The main entrance is on Colwith Road at the rear of the school. The majority of children approach the school from Fulham Palace Road (Figure 3c), which is a very busy road with large number of buses and HGVs.

Holy Trinity C of E (HT) Primary School is in the Royal London Borough of Kensington & Chelsea, north of Sloane Square. The school has two sites, one located north of Sedding Street (Figure 3d), and the other adjacent to Cadogan Gardens and Pavilion Road. Both sites are situated just north of the busy A3216, which is used by large number of buses, taxis and service vehicles and is the main source of emissions locally.

[7]Greater London Authority. The Mayor's School Air Quality Audit Programme. Programme Report. (2018).

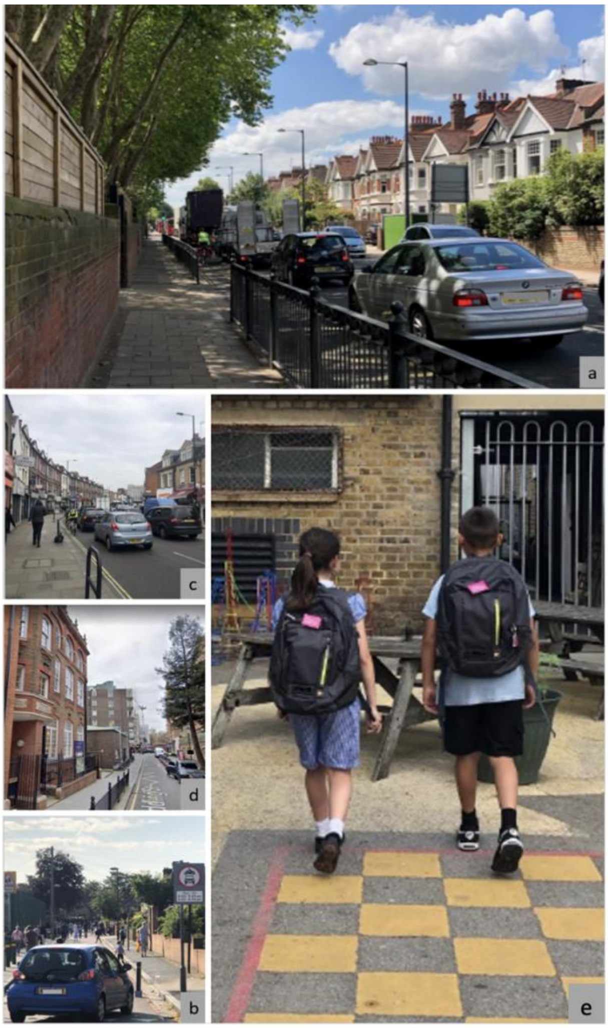

Figure 3. Schools neighborhoods (a)ES, (b)HA, (c)ME, (d)HT (e)children from HA carrying the backpack

"I wanted to do this project to see how much we are putting our bodies and lungs at risk" *(Child, ME - year 4)*

For most of the participating schools the catchments areas are relatively small, with the majority of children living within a short walking distance. The exception is HT, which is a faith school and has a wider catchment area, leading to a wider range of transport modes to get to and from school. A total of 258 children across the five schools took part in this study. Children's age ranged between 6 and 11 years old (year 1 to year 6). Most of these children were ambassadors within their school e.g. members of school council.

3| LEARNING ABOUT AIR POLLUTION

We began our study by inviting all the participating children to an air quality educational lesson delivered by King's College London's air quality scientists and Dyson engineers (Figure 4). Children learned about air pollution causes and effects and about how air pollution is normally measured by scientists and how they themselves could be a 'scientist' too by helping measure air pollution using special backpacks with state-of-the-art air quality sensors developed by Dyson.

Figure 4. Air quality education lesson at one of the participating schools

The education session was carefully designed to take into consideration the audience. The presentation avoided the use of technical jargon and explained difficult concepts with clear practical examples.

"The project made the children feel like real scientists, like they were taking part in something real" *(Teacher - year 4)*

4| DATA COLLECTION AND ANALYSIS

Weighing just over 1 kg, the air pollution sensor fitted into a lightweight normal school bag (Figure 5), leaving enough room for children to carry their daily essentials. The bag simultaneously measured the two pollutants of most concern in London NO_2 and $PM_{2.5}$. Importantly, the backpack also recorded

GPS location, allowing pollutant concentrations to be matched to location.

Children carried the backpack for five consecutive days (Monday-Friday). The air pollution sensor turned on automatically between 8:00 - 11:00 am and again in the afternoon between 2:00 - 8:00 pm. Information about how to temporarily turn off the GPS tracker was given to all parents of participating children.

Figure 5. The "I am an air quality scientist" backpack was given to the children to monitor air pollution levels.

Each participant's exposure to NO_2 and $PM_{2.5}$, as well as their GPS-location were collected at a 1-second interval and stored on a microchip within the backpacks' logging unit. The power to the logging unit was provided by a battery, which was securely locked in a separate compartment in the backpack.

Children were asked to fill a commute diary, telling us the mode of transport they used to and from school during the monitoring week. In order to safeguard the participants' anonymity, the GPS coordinates around 100 metres radius of the children's homes were removed from the analysis results. To compare typical outdoor concentrations with the personal measurements, we obtained NO_2 and $PM_{2.5}$ concentrations from the nearest London Air Quality Network (LAQN, www.londonair.org.uk) long-term fixed monitoring site during the period the children were conducting their measurements.

After the study, all of the backpacks were placed on the roof of the LAQN reference monitoring station in Honor Oak Park and monitored continuously for five days (Figure 6).

Figure 6. Backpacks at Honor Oak Park monitoring station

This comparison period allowed us to test the precision and accuracy of the backpacks sensors, and calibrate the measurements taken by the children. The process indicated that the $PM_{2.5}$ sensors in all backpacks performed very well and consistently. The NO_2 sensors' performance was more variable, therefore the following results for NO_2 should be considered indicative of approximate concentrations.

In order to analyse such a large volume of data, we developed a unique statistical method to examine the variation in pupils mean exposure to the air pollutants NO_2 and $PM_{2.5}$ in different settings (at home, at school and when travelling to and from school) during a typical school week.
The travel diaries and GPS data were used to split the school commutes into travelling by car or bus, walking along main roads and walking along back roads. Other forms of transport, such as train or Tube, were too infrequent to produce robust results.

5| OUTCOMES OF THE STUDY

Thanks to our enthusiastic and dedicated young air quality scientists, the unique data set gathered gave us the opportunity to compare the different routes and modes of transport used by the children, allowing us to quantify different exposure levels.
The data gathered also helped us determine where children may have been exposed to elevated concentrations, which forms of transport were more polluting, and to contrast air quality within and surrounding the school.

Child exposure to air pollution during a typical school week

We identified the levels of air pollution children are exposed to during a typical school week when travelling to and from school and while at school. This is particularly important because we can then determine when during a typical school day, children are more likely to be exposed to higher levels of air pollution. We found that on average, across all schools, the children were exposed to levels of NO_2 five times higher when travelling to school in the morning, and four times higher travelling home in the afternoon, than while at school (Figure 7). This reflects typical fluctuations in air pollution levels throughout the day. Air pollution levels tend to be higher during the morning rush hour.

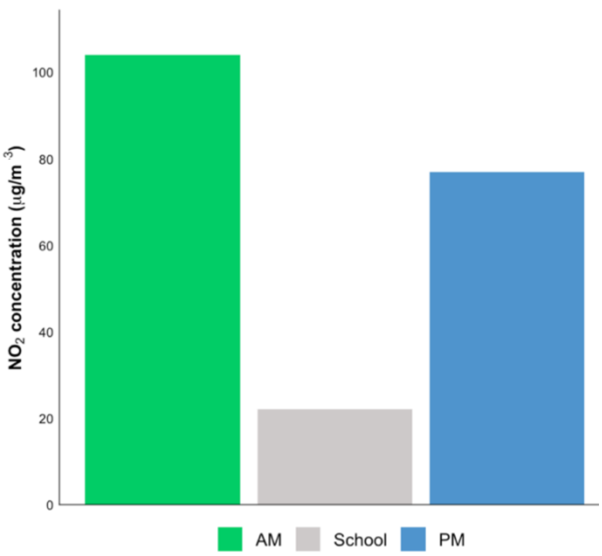

Figure 7. Average NO_2 concentrations over the monitoring period across all participating schools.

Levels of $PM_{2.5}$ were also higher during the journeys (Figure 8), but the difference was not as great. This is because $PM_{2.5}$ pollution comes from many sources other than vehicle exhaust. A large proportion of the $PM_{2.5}$ in London travels from Europe and beyond. In contrast, most of the NO_2 pollution the children breathed came from vehicles travelling along their school routes.

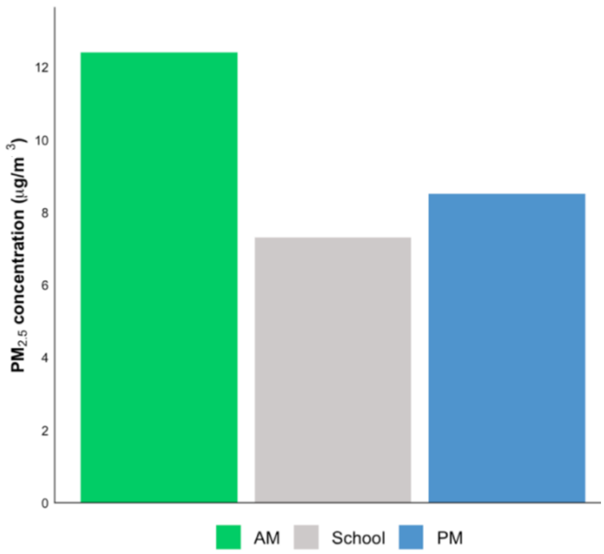

Figure 8. Average $PM_{2.5}$ concentrations over the monitoring period across all participating schools.

"Because the road is so busy outside, parents are concerned about the air quality inside the school, how is affecting the children and what is the difference from outside".
(*Teacher - year 4)*

Figure 9. Children at ES school during the education lesson

Travelling to and from school

Travel to and from school usually occurs during the most polluted times of the day and can account for a large proportion of a child's daily exposure. During the monitoring week, the 258 children that took part in this study carried out more than 2,000 journeys (including to and from school). We asked them to fill in a diary telling us which mode of transport they used to travel each of these journeys (Figure 10).

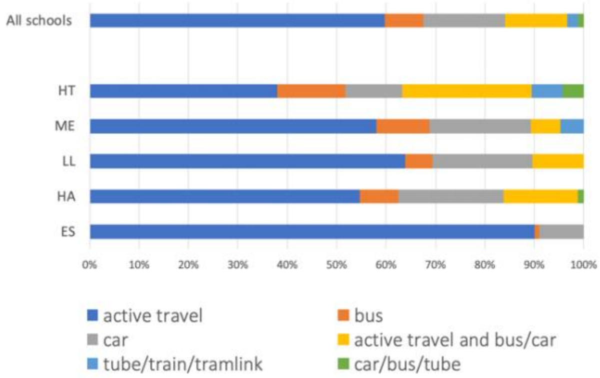

Figure 10. Transport modes of participating children during the monitoring period.
**Active travel: walk/scoot/cycle*

For the majority of the participating schools, these journeys were made either on foot (walking), scooter or bicycle which is very good news, as this is the healthiest and least polluting choice. From the parents surveyed 45% said that their journey to school takes on average between 0-10 minutes, 24% said between 10-15 minutes and 22% between 15-30 minutes. Just 5% reported that their children commute to school takes longer than 45 minutes.
When we asked parents, what influenced how their children travel to school, 28% said that "convenience" was the most influencing factor, 18% said "speed" and 18% said "habit". Other factors such as "getting physical activity" "reducing environmental impact" and to "breathe clean air" were reported to be less important.

We also asked parents if they thought that their child's route to school was affected by air pollution, to which 52% responded "A lot", 33% responded "A bit", 10% didn't know and 5% responded "Not at all".

The results from this study indicate that during the monitoring period, across all schools, the children that walked to and from school through busy main roads were exposed to higher levels of air pollution (NO_2) than those that chose to travel through back streets (Figure 11). Air pollution levels for $PM_{2.5}$ presented a similar pattern (Figure 12).

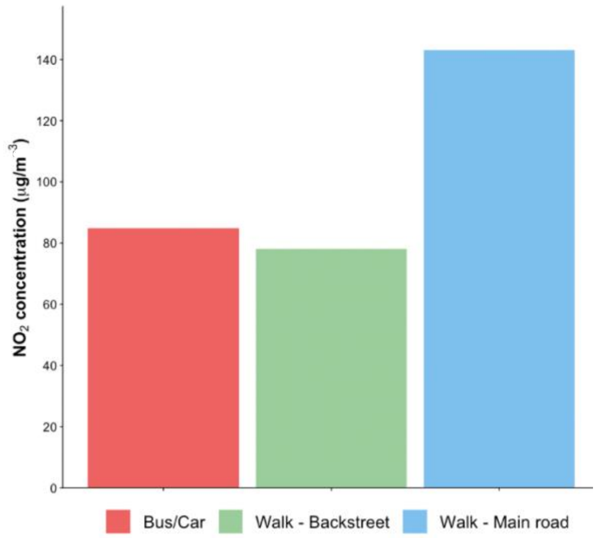

Figure 11. Average NO_2 concentrations across all schools, according to mode of transport.

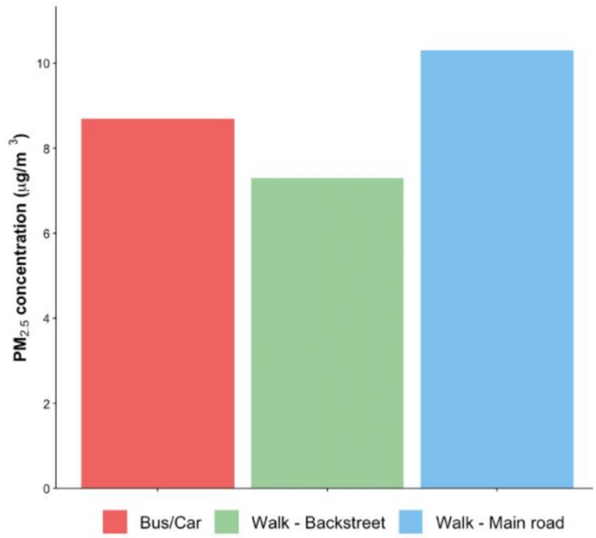

Figure 12. Average concentrations of $PM_{2.5}$ across all schools, according to mode of transport.

Previous studies have shown that pedestrians will in general be exposed to lower levels of air pollution than those travelling the same route in a car or bus[8] (most cars do not provide protection from traffic fumes), in this study we identified that children that walked/scooted and cycled to school through busy roads may also have been exposed to higher levels of air pollution (Figure 11 and 12).

The results obtained from our $PM_{2.5}$ measurements (Figure 14) showed that there is a clear difference between concentrations recorded on main roads and back streets. Children that walked through back roads, across all schools, were exposed to lower levels of air pollution ($PM_{2.5}$) than those who opted for walking along the main roads.

This study also identified that, across all participating schools, children that walked, scooted and cycled through back streets were exposed to lower air pollution ($PM_{2.5}$) exposure levels compared to children that were driven to school or that took the bus. Figure 15 shows the levels of air pollution ($PM_{2.5}$) present in one of our participating schools (HA) surrounding areas during the afternoon school commute.

Figure 13. Children from ME carrying the backpacks.

"With this study I learnt that you can actually take more pollution in the car than on the streets, which is surprising because you think that you are sealed up from all the pollution in the car"
(Child, ES - year 5)

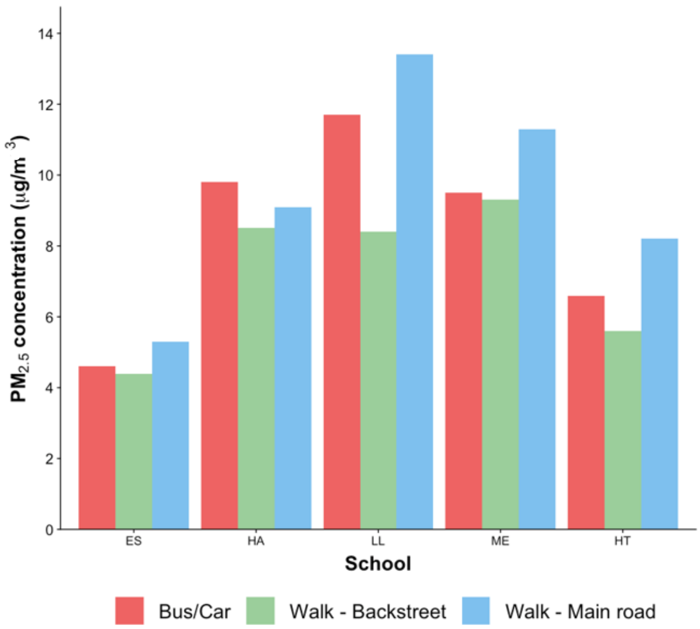

Figure 14. $PM_{2.5}$ levels over the monitoring period for each of the participating schools, according to modes of transport.

[8] Gilliland, J., et al. (2019) Is active travel a breath of fresh air? Examining children's exposure to air pollution during the school commute. *Spatial and Spatio-temporal Epidemiology*

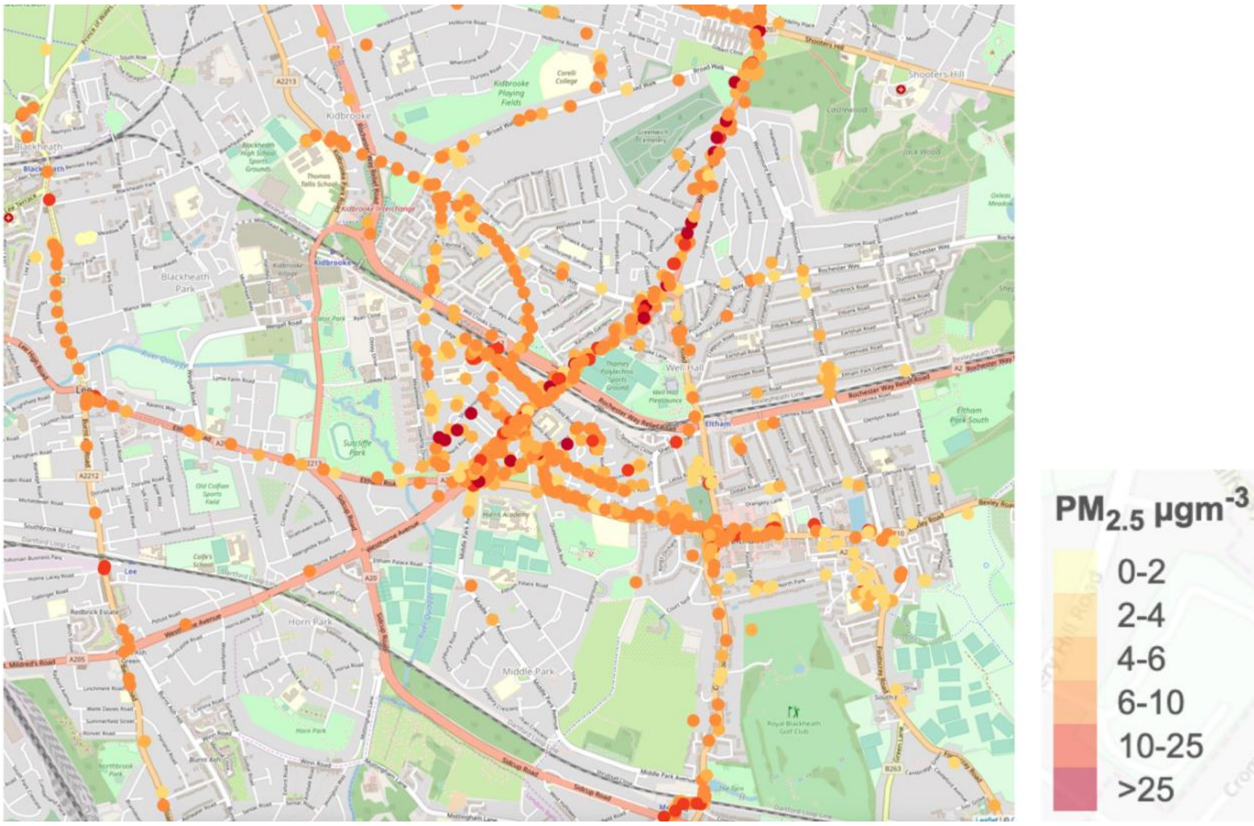

Figure 15. All of the $PM_{2.5}$ pollution measurements that the backpacks recorded at HA school during the children's trips back home from school during the monitoring week (µg m-3). Darker reds mean higher pollution levels. Note that measurements taken near participants homes have been removed.

This study shows that there is a clear difference in the air pollution levels (NO_2) recorded between main roads and back streets across all participating schools (Figure 16). However, at times, high air pollution levels can also be present in "back steets" which can become rat-runs for drivers, particualrly during rush hours. Additionally, and as highlighted by parents and teachers, parents that drive children to school can also contribute to high levels of air pollution on back streets as they tend to use these roads for dropping off/picking up children while leaving the car engine on (idling).

Air pollution concentration levels can also be elevated when pollutants get trapped on narrow streets lined up with tall buildings in the vicinity of the schools. This is particularly the case for schools located in central London like HT.

Unlike $PM_{2.5,}$ at some schools, NO_2 levels within the car/bus were lower than those measured in back streets (Figure 16). This is a surprising result which may reflect the relatively low number of car journeys taken by the participating children (Figure 10) and the variability of the NO_2 sensor.

In Figure 17, we provide an example of the maps we created for each of the participating schools to show the levels of air pollution (NO_2) present in the surrounding areas during a school commute.
In this map we can see that main roads and busy junctions show up as more polluted, while parks and quiet back roads are cleaner (yellow dots). We can also observe that even quieter roads can show occasionally high levels of pollution (red dots), as polluting vehicles drive past but they are cleaner on average.

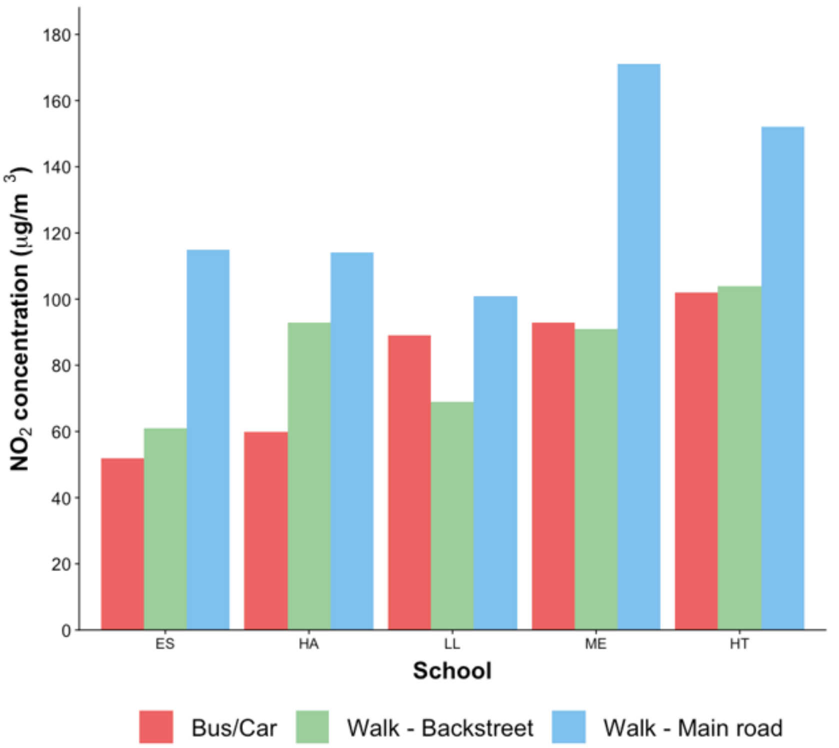

Figure 16. NO_2 levels over the monitoring period for each of the participating schools, according to modes of transport.

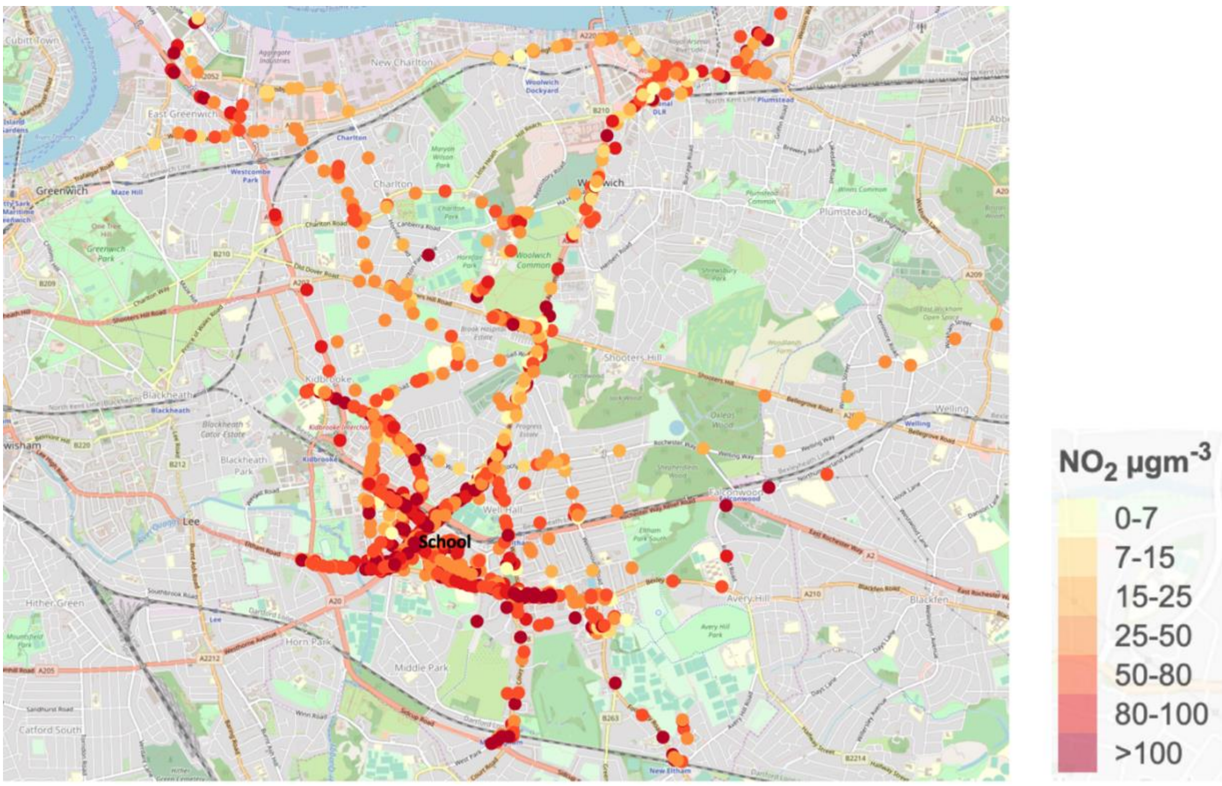

Figure 17. All of the NO_2 pollution measurements that the backpacks recorded at HA school during the children's trips back home from school during the monitoring week (µg m^{-3}). Darker reds mean higher pollution levels. Note that measurements taken near participants homes have been removed.

The air quality measurements collected during this study were mostly from the family's local area, during a typical school week. This made the findings from the monitoring measurements relevant to the children and their parents daily school commute, including the routes and modes of transport they choose to get to school. In general, children across all participating schools reported that taking part in this study had boosted their level of air pollution awareness and hence, their understanding of the issue. Through this understanding, children had the opportunity to analyse their own situations (e.g. places and times where they were most likely to be exposed to air pollution) and to propose solutions to reduce exposure to harmful pollutants and or reduce their own contribution to air pollution.

"I was a bit scared before the project but now I am happy to know that I can do something about it because I didn't know anything about it but now I know that I could walk through the parks or back roads and try to stay away from traffic as much as possible" *(Child, HA - year 4)*

Credit Dyson

6| REDUCING CHILDREN'S EXPOSURE TO AIR POLLUTION

- Choose a low pollution walking or cycling route to school by avoiding busy roads or using our route planner https://www.london.gov.uk/what-we-do/environment/pollution-and-air-quality/clean-air-route-finder.
- Walking, scooting or cycling to school will not only expose children to less pollution, it will provide all of the benefits of exercise and expose children classmates to less pollution by improving air quality around the school.
- If the school is close to a major road, ask what steps have been taken to protect pupils from air pollution in the school buildings and playground.
- Ask to see the school's travel plan and check that is has consideration for active travel and local air quality.
- If you have to drive, close windows and vents when driving along busy roads or sitting in queuing traffic, while setting the car's ventilation system to recirculate.

Acknowledgements

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Monitoring backpacks were designed and provided by Dyson Ltd following a competitive selection process. We are grateful to Dyson for their voluntary involvement in the educational programme.

Ethical approval: Approved by the King's College Research Ethics Committee, King's College London.