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The Adverse Health Effects of Exposure to Dust on the London Underground

Study Management Group

Principal Investigator: Professor Paul Cullinan

Co-investigators: Dr David Green, Dr Johanna Feary, Dr Emma Marczylo, Dr Chamishani Rathmalgodi, Justie Mak

Sponsor

Imperial College London is the main research Sponsor for this study. For further information regarding the sponsorship conditions, please contact the Head of Research Governance and Integrity.

This protocol describes the Adverse Health Effects of Exposure to Dust on the London Underground study and provides information about procedures for entering participants. Every care was taken in its drafting, but corrections or amendments may be necessary. These will be circulated to investigators in the study. Problems relating to this study should be referred, in the first instance, to the Principal Investigator.

This study will adhere to the principles outlined in the Data Protection Act 2018 and General Data Protection Regulations (Europe) and other regulatory requirements as appropriate.

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1. INTRODUCTION

1.1 Background

To include a review of previous studies

Background

The London Underground (LU) first opened in 1863, making it the oldest subterranean transport system in the world. Today[1], it provides around 2.8 million journeys a day to those travelling in London, and employs over 19,000 staff [1, 2]. Those who use and work on the LU are exposed to varying concentrations of underground particulate matter (PM) air pollution. While the adverse health effects of ‘ambient’ (outdoor) PM air pollution have been widely studied and are known to contribute to increases in mortality and morbidity, the health effects of PM from other environments are often less well understood [1-3]. One such environment is the LU, where PM differs in both physical and chemical composition to ambient PM.

Exposure measurements

There are six published sets of measurements of LU exposures. The first were undertaken in 1999, where three commuters were monitored while travelling for 1.5 hours on the Piccadilly Line; average, personal PM_5 concentrations were between 709 and 893µg/m^3 [4]. A further set of personal measurements were made in 1999, measuring exposures of 10 office workers on their daily commutes on the LU over 7 days; the average $PM_{2.5}$ concentration was 246µg/m^3 [5]. Personal sampling carried out by 18 volunteers four times a day on three routes, starting at Tottenham Court Road, Kensal Green, and Putney Bridge, and ending at South Kensington reported $PM_{2.5}$ concentrations ranging from 12.2 to 371.2 µg/m^3 [6]. Measurements of $PM_{2.5}$ made in 2005 on three consecutive days from 7am to 5pm on three selected platforms – Holland Park, Hampstead, and Oxford Circus stations - ranged from 270-480µg/m^3, while mean shift concentrations in the drivers’ cabs on the Central, Northern, and Victoria lines ranged from 130-200µg/m^3 [7]. In 2019, Saunders *et al* [8] undertook personal measurements on the entirety of the LU network, to find $PM_{2.5}$ ranging between 68-306µg/m^3; measurements were taken by a researcher every 10 seconds while travelling across all 11 lines. Personal measurements were again undertaken by researchers across the network by Smith *et al* [9]; exposure measurements on each train line were taken between two and five times over separate days, totalling in approximately 31 hours of sampling. A wide range of $PM_{2.5}$ concentrations were found, from 4-885µg/m^3.

In Smith’s measurement campaign, mean $PM_{2.5}$ mass was around 15 times greater (302µg/m^3) than at background (18µg/m^3) and roadside (26µg/m^3) sites [9]. While the (mean) mass concentration on the underground was higher, particle number counts (PNC) were lower, reflecting a higher proportion of larger particles than in ambient air [9]. Smaller particles are generally considered more hazardous, as they allow a greater platform for free radical reactions; in addition, they penetrate more deeply into the airways and more readily induce lung inflammation and tissue damage. The lower PNC and larger particle size may indicate that, despite a higher mass concentration, there are fewer health effects associated with underground PM compared to ambient PM [10].

Apart from physical differences, there are also differences in chemical composition. On the LU, Fe_2O_3 made up 47% of $PM_{2.5}$ mass [9]; in line with Sitzmann’s observation that 64% of particles were rich in iron and/or silicon [4]. In contrast, $PM_{2.5}$ sampled at four roadside sites

[1] in non-pandemic circumstances

in London (High Holborn, Elephant and Castle, Park Lane) and Birmingham (Selly Oak) was made up of just 6% iron-rich dust, with the remaining made of 63% carbon, 23% ammonium salts, calcium sulphate, salt, and bound water [11]. The difference in chemical composition is presumably due to a difference in sources. On the LU, there is an abundance of metallic components, such as steel (tyreless) wheels and rails, cast-iron collector shoes, and silica brake pads, which are constantly in frictioned contact [12]; the increased concentrations of iron are seen consistently in underground systems around the world. There are also fewer combustion particles of the type commonly found in the ambient atmosphere from traffic and wood burning [13]. The metallic components of PM may contribute to adverse health effects through the facilitation of redox reactions and DNA strand damage [14].

Health effects

Loxham and Nieuwenhuijsen [15] undertook a systematic review of studies of adverse health effects of PM from underground railway systems published up to the end of 2018. Among the human studies reviewed, there was little evidence indicating that exposures to underground PM have greater adverse health effects than those from ambient PM.

Eight studies examined the short-term health effects using panels of subway workers or volunteers, with outcomes were measured before and after work shifts or travel on a subway that studied a variety of outcomes. Five studies took place in Stockholm, Sweden, and the remainder in Taipei, New York City, and Tehran. Among the four studies looking at employees before and after work shifts, sample sizes ranged from 39 to 81. In the Stockholm studies, no changes were found in lung function or FeNO, and acute changes in inflammatory markers fibrinogen and PAI-1 were unrelated to subway PM exposure [16, 17]. In a New York study, only urinary 8-isoprostate, a marker of oxidative stress, was associated, though not significantly, with cumulative underground exposure. At the group level, there were no consistently elevated biomarkers in subway workers compared to office workers and bus drivers [18]. In Tehran, urinary 8-hydroxy-deoxyguanosine (8-OHdG), a marker for oxidative DNA damage, was found to be significantly higher in workers who work in subway tunnels compared to underground employees who did not work in subway tunnels [19].

In four short-term studies that recruited non-employee volunteers, three took place in Stockholm and one in Taipei. Sample sizes ranged from 16 to 120. In the Swedish studies, there were no changes in lung function, or increases in inflammatory markers – plasma fibrinogen, Treg cells and 9 oxylipins – assayed in broncho-alveolar lavage fluid [20-22]. The study in Taiwan found that travel by subway had a smaller effect on heart rate variability than travel by bus, car or on foot [23].

1.2 Study Rationale

To include: reason for doing study, research question and hypothesis

Research Gaps

Underground transport systems, in London and elsewhere, are regularly used by very large numbers of passengers who can in this way incur high exposures to particulate pollution. While much is known about the adverse cardiorespiratory health effects of exposure to 'ambient' PM, it may be unwise to extrapolate this knowledge to underground exposures, which, at least in London, are qualitatively very different from those encountered above-ground.

There is very little published research into the health hazards of underground travel and almost all of it has been undertaken in relation to a single system (Stockholm). While the findings have been encouraging, the studies have been limited in both scope and size, and their findings may not be applicable to travel on the LU. Moreover, studies of underground employees have so far been limited to men; 24% of the current LU workforce is female.

In their report on the topic in January 2019, the UK Committee on the Medical Effects of Air Pollution (COMEAP) concluded that "much work is still needed to investigate the relationship between subway PM exposure and any health effects". While the subject of the report was the travelling public, the Committee recognised the value of research into the health of the LU workforce for whom exposures are often higher and in whom any signals of adverse health outcomes would be expected to be stronger. The first of their three recommendations for further research explicitly calls for “Investigation of ways to increase the usefulness of employment health records of those working in the [London] underground to assess potential adverse health effects of underground exposures”. The proposal presented here aims to fulfil this recommendation.

Research question

Is exposure to PM on the LU among employees associated with higher rates of sickness absence for cardiorespiratory illnesses?

Hypothesis

We hypothesise that variations in the rates of sickness absence from cardiorespiratory disease between groups of employees on the LU will reflect their relative exposures to underground PM.

2. STUDY OBJECTIVES

What are you hoping the study achieves, list the primary, secondary and other study objectives?

Aim/Primary Objective

This short-term, retrospective cohort study is a response to the COMEAP recommendation ‘to [use] employment health records of those working in the LU to assess potential adverse health effects of underground exposures.’

Objectives:

- allocate LU workers to distinct exposure categories based on their job titles, descriptions, and locations of work
- develop a specific job-exposure matrix by modelling category-specific exposures with measurements taken across the LU
- identify LU workers employed between 01/01/2014 and 31/12/2019 and collect information on their job(s) and their sickness absence data from the LU employment (‘SAP’) database
- calculate sickness absence rates due to respiratory or cardiac illnesses for each exposure category

3. STUDY DESIGN

Detail how this study will be conducted from how you will obtain the secondary data
Type of study: what information does the data contain
consent forms

Type of study: dynamic, retrospective cohort study
Duration: 01/01/2014-31/12/2019
Subjects: LU staff

Study population

The study population will consist of all LU staff employed between 01/01/2014 to 31/12/2019. This includes those who joined or left in this period.

Our exclusion criteria consist of non-TfL employees whose sickness absence data are not recorded in the LU employment ('SAP') database.

Data collection

Data will be collected from pre-existing databases at the LU. The data we will require include employment records from the Human Resources (HR) department and sickness absence records, both of which are held on the SAP database.

First, we will create a job exposure matrix (JEM) to categorise LU employees into distinct groups reflecting their relative exposures to underground PM. Staff will be allocated to exposure categories based on their job titles, duties undertaken over a shift, and where in the network they undertake them. The exposure categories will form the basis of a job exposure matrix (JEM) and dictate the measurement campaign outlined below; the JEM will be created prior to data analysis.

Next, a list of over 2000 sickness absence illness codes, provided by TfL, will be filtered to include only the relevant illnesses for our study. The illness codes corresponding to the selected cardiorespiratory illnesses will be used to download sickness absence data for the employees in the cohort. In addition, total episodes of absence (not otherwise classified) will be used as a proxy for individual sickness absence behaviour.

The following data will be abstracted from employment and sickness absence records. Data will be pseudonymised for increased data protection.

- Sex
- Age range
  - o <25, 25-29, 30-34, 35-39, 40-44, 45-59, 50-54, 55-60, >60
- Job title and place of work; multiple where relevant
- Date of employment/placement start
- Date of employment/placement end
- Episodes of absences between 01/01/2014 and 31/12/2019 due to cardiorespiratory illnesses with, for each episode,
  - o date started

    - date finished
    - reason for absence (classified based on illness codes)
- Total episodes of sickness absence (unclassified by reason) between 01/01/2014 and 31/12/2019

Each employee will be given a unique participant identifier in the form of an ID number. The names and addresses of employees are not required.

Exposure Measurement Campaign and Category-Specific Modelling

To model exposure to tunnel dust for each exposure category, we will undertake a measurement campaign throughout the LU network to apply quantitative estimates of PM exposure to each exposure category.

We will invite selected employees to wear a lightweight personal dust monitor throughout their working shift, and in addition, undertake a series of stationary measurements on representative station platforms, gates, and in drivers' cabins. These measurements will also give us insight into temperature, and humidity, as well as how PM concentrations vary due to seasonal changes.

In addition to measurements that will be collected, we will explore the value of measurements previously carried out by the LU to create models of site-specific exposures for each exposure category. Measurements taken will contribute to the JEM.

Data analysis and statistics

The primary outcome measure is the number of spells of absence for cardiorespiratory illness. Cause-specific frequencies for the selected respiratory and cardiac illnesses for each exposure group will be calculated and Poisson regression used to explore any associations between exposure to PM and episodes of sickness absence. Adjustment will be made for variables such as age, gender, season, and total episodes of sickness absence. We will explore an alternative outcome measure of total number of days of coded sickness absence.

4. SECONDARY DATA

4.1 Database

Describe where you are obtaining the data from, how and any permissions you have to use/access the data.

The data used for this study will be provided by the LU HR department. Employment records, employee details, and sickness absence data are available from the HR SAP (System Analysis and Software Development) database.

Permission has been obtained from TfL and the LU through a data sharing agreement in an Academic Confidentiality Agreement contract signed between TfL and Imperial College on March 31, 2021 (attached). A further letter of permission has been provided by the LU HR department, confirming approval for data sharing and analysis.

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5. REGULATORY ISSUES

5.1 Ethics approval

The Principal Investigator has obtained approval from the Head of Department and approval from the Research Governance Integrity Team (RGIT).

5.2 Consent

Do you have any evidence of participants consent for their data to be used in other studies other than what it was originally collected

Because our study cohort will consist of tens of thousands of participants, it is unrealistic to contact each member of the study individually to inform them of the use of their data.

We have devised a communications strategy as follows:

Current employees

For those who joined after 2018, their employee privacy notice states that "Transport for London (TfL) may use aggregated or depersonalised employee data for analysis purposes – for example to ensure that we have an efficient and diverse workforce – or for occupational health purposes. Individuals will not be identified using this information."

While this statement was not included for employees who joined prior to 2018, when the General Data Protection Regulations (GDPR) and Data Protection Act (DPA) of 2018 were brought into effect, employees were notified about the updated version of the privacy notice through email.

In addition, a privacy notice with information about our study, the data being collected, our legal basis for processing data, and our contact details will be distributed to current employees through the following channels:

1. The internal TfL employees' newsletter
2. Stakeholder committee meetings
   - LU Air Quality Partnership Meeting - meeting with Trades Unions on air quality management, chaired by London Underground Asset Operations.
   - Air Quality Implementation Group - internal GLA/TfL meeting, chaired by the London Deputy Mayor for Environment & Energy, tracking progress of the Mayor's air quality programme. Updates on London Underground Air Quality work are taken to this meeting on an ad-hoc basis.
   - London Assembly Environment Committee - public meeting which has covered LU Air Quality
3. An upload onto a publicly available TfL website

A copy of this notice is attached

Former employees

For those who were employed between 01/01/2014 to 31/12/2019 but have since left TfL, we will communicate through the pensions' newsletter and the annual pensions meeting. A link will be provided to the privacy notice which will be uploaded onto a publicly available TfL link, as mentioned in point 3 above. Furthermore, the study will also be publicised through the annual pensions meeting.

5.3 Confidentiality

Only applicable if non-anonymised data is being used
The Principal Investigator will preserve the confidentiality of participants and fulfil transparency requirements under the General Data Protection Regulation. Data and all appropriate documentation will be stored for a minimum of 10 years after the completion of the study, including the follow-up period.

5.4 Funding

Transport for London are funding this study.
Any per participant payments, investigator payments should be detailed here

5.5 Audits

The study may be subject to inspection and audit by Imperial College London under their remit as sponsor and other regulatory bodies.

6. STUDY MANAGEMENT

The day-to-day management of the study will be co-ordinated through Professor Paul Cullinan.

The team will meet on a weekly basis, with additional meetings if and when necessary.

1. Name	Professor Paul Cullinan
2. Position *Incl. organisation, company, institution*	Professor in Occupational and Environmental Respiratory Disease, National Heart and Lung Institute, Department of Medicine, Imperial College London
3. Role in the study *(what contributions you will make and relevant experience)*	Long academic career in the epidemiology of occupational respiratory disease with experience in many types of study design including cohort studies. Recently completed sickness absence study of Covid-19 in NHS staff. MSc in epidemiology and biostatistics.
4. Email *Work not personal*	p.cullinan@imperial.ac.uk

1. Name	Dr David Green

2. Position *Incl. organisation, company, institution*	Senior Research Fellow, Environmental Research Group, Imperial College London
3. Role in the study *(what contributions you will make and relevant experience)*	Co-principle investigator; oversight of exposure measurements; co-supervisor to Justie Mak, PhD student. Extensive experience of exposure measurements on LU and elsewhere
4. Email *Work not personal*	d.green@imperial.ac.uk

1. Name	Dr Johanna Feary
2. Position *Incl. organisation, company, institution*	Senior Clinical Research Fellow, National Heart and Lung Institute, Imperial College London
3. Role in the study *(what contributions you will make and relevant experience)*	Co-chief investigator; co-supervisor to Justie Mak, PhD student. Academic clinician in occupational respiratory disease.
4. Email *Work not personal*	j.feary@imperial.ac.uk

1. Name	Dr Emma Marczylo
2. Position *Incl. organisation, company, institution*	Principal Toxicologist, Centre for Radiation, Chemical, and Environmental Hazards, Public Health England
3. Role in the study *(what contributions you will make and relevant experience)*	Co-chief investigator; co-supervisor to Justie Mak, PhD student
4. Email *Work not personal*	emma.marczylo@phe.gov.uk

1. Name	Dr Chamishani Rathmalgoda
2. Position *Incl. organisation, company, institution*	Lead Consultant Occupational Physician, Transport for London
3. Role in the study *(what contributions you will make and relevant experience)*	Co-chief investigator. Extensive experience occupational health including sickness absence management
4. Email *Work not personal*	chamishanirathmalgod@tfl.gov.uk

1. Name	Justie Mak
2. Position	PhD student, Imperial College London

Incl. organisation, company, institution	
3. Role in the study *(what contributions you will make and relevant experience)*	PhD student, MSc in Global Air Pollution and Health
4. Email *Work not personal*	j.mak21@imperial.ac.uk

7. PUBLICATION POLICY

The study publication policy should be described in full

We will aim to publish our findings in peer-reviewed scientific literature under open access. TfL will have sight of publications prior to submission, but will have no right to amend them or delay/prevent submission. Authorship will be limited to those who have made a substantive intellectual contribution to the work.

We will provide reports and accessible summaries to TfL, which will be circulated to their staff and uploaded to other communication channels.

The study will be registered in the ISRCTN registry.

8. REFERENCES

List of useful and relevant references for the study

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