USE OF NOVEL SENSORS TO ASSESS HUMAN EXPOSURE TO AIRBORNE POLLUTANTS AND ITS EFFECTS ON COGNITIVE PERFORMANCE

by

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Abstract

Exposure to air pollution can cause adverse health effects, may also adversely affect the central nervous system (CNS) and affect cognitive performance and may lead to mortality. Epidemiological studies depend on central site monitors as surrogates to assess personal exposure to air pollution, which can be inaccurate because they do not assess personal exposure in a variety of activities and microenvironments.

This thesis aims to assess the level of misclassification in data from central site monitors by using portable modern sensors with high temporal resolution to characterize personal inhaled doses of black carbon (BC), $PM_{2.5}$, and ultrafine particulates (UFP), and compare the measurements with surrogate exposure metrics. It also seeks to identify contributing activities and sources associated with the highest concentrations of the three pollutants, and to determine the contribution of these activities and microenvironments to personal exposure, and to study the impact of short-term exposure to air pollution on cognitive function.

The study took place in Birmingham, UK, with a sample size of 40 healthy adult subjects, whose exposure to the three pollutants above was monitored using portable modern sensors. These measurements were systematically and concurrently compared with the measurements from central sites and at the subjects' houses. Each subject was sampled for 4 consecutive days. Cognitive performance was assessed by using three cognitive tests. The first important findings is that central site monitors are not a good surrogate for personal exposure. Secondly, travelling in

vehicles is linked to the highest concentrations of the three pollutants, while other outdoors activities and outdoors commuting are linked to the highest concentrations of BC and $PM_{2.5}$, cooking is linked to the highest concentrations of UFP, and activities and time spent indoors are the highest contributors to personal exposure. Thirdly, the results provide strong evidence that short-term exposure to $PM_{2.5}$ from candle burning and commuting has an adverse effect on cognitive performance.

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Abbreviations

95ile: 95th percentile

ADA: Automatic detection accuracy

ADS: Automatic detection speed

AM: arithmetic mean

AMIPB: Adult Memory Information Processing Battery

ANOVA: analysis of variance

AVLT: Auditory Verbal Learning Test

BBB: brain-blood barrier

BC: black carbon

BDNF: brain-derived neurotrophic

BSD: black soot deposition

CAB: Cognitive Assessment Battery

CNS: central nervous system

CO: carbon monoxide

CPT: Continuous Performance Test

CS's: central sites

CSA: Controlled search accuracy

CSS: Controlled search speed

DEFRA: Department for Environment food and Rural Affairs

E: electricity

EC: elemental carbon

eNO: exhaled nitric oxide

ELAPSE: Effects of Low-Level Air Pollution: A Study in Europe

ETS: environmental tobacco smoke

G: gas

H: home

H_2S: hydrogen sulfide

HbCO: Carboxyhemoglobin

HC: hydrocarbons

HEI: Health Effects Institute

HEPA: High Efficiency Particulate Arrestance

K-S: Kolmogorov-Smirnov test

Max: maximum

Min: minimum

MMSE: Mini-Mental State Examination

M-W: Mann-Whitney test

NO: nitrogen monoxide, or nitric oxide

NO_2: nitrogen dioxide

NO_x: nitrogen oxides

NTR: quiet road

O_3: ozone

ONA: optimized noise-reduction algorithm

OPS: optical particle sizer spectrometers

PE: personal exposure

PM: particulate matter

$PM_{2.5}$: particulate matter with diameter less than or equal to 2.5 micrometers

PM_{10}: particulate matter with diameter less than 10 micrometers

PNC: particle number concentration

PVT: Psychomotor Vigilance Test

QD: quartile deviation

SD: standard deviation

SDS: Symbol-Digit Substitution

SOP: standard operating procedure

SRT: - Simple Reaction Time

THC: total hydrocarbons

TR: Busy road

UFP: ultrafine particles

VOCs: volatile organic compounds

CHAPTER 1: INTRODUCTION

Air pollutants result from natural sources (i.e. volcanoes) and/or anthropogenic activities (i.e. industrial facilities), which contain hazardous chemical pollutants, such as volatile organic compounds (VOCs), nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter ($PM_{2.5}$, PM_{10}), heavy metals and ozone (O_3). These pollutants have adverse effects on human health, both acute and chronic, as well as affecting mortality (e.g. cancer, cardiopulmonary disease) and on the environment as well such as global warming and acid rain (Geller et al., 2006).

The industrial revolution resulted in an increase of pollutants emissions from human activities, such as the combustion of coal for cooking, heating, and transportation. The effects of air pollution on health were underestimated, until the occurrence of air pollution incidents in several places. In the Meuse Valley smog incident in Belgium, in 1930, a temperature inversion trapped the pollutants from factories, increasing the concentration of air pollutants, and causing the death of 60 people during the week of the incident. In 1948 the Donora smog incident in Pennsylvania, the effect of a temperature inversion on heavy smoke emitted by factories was an accumulation of pollutants in the air. This resulted in 20 deaths, and mild, moderate, and severe upper respiratory symptoms reported by 90% of the affected group, with coughing the most reported symptom. The London photochemical smog of 1952 was also caused by a temperature inversion trapping pollutants from coal fires, vehicle exhaust and power

plants, and caused thousands of deaths (Ciocco and Thompson, 1961, Firket, 1936, Ministry of Health, 1954, Satoh, 2009).

As a result, air pollution has become a major environmental health problem, prompting many studies related to this subject, including short-term and long-term studies on the effects of air pollution on health (Brunekeef and Holgate, 2002), such as PM (Ostro et al., 1996, Schwartz, 2001).

Air pollution affects different physiological systems and human organs, such as the lung and heart. Pope et al. (2002) concluded that long-term exposure to UFP is associated with lung cancer, and cardiopulmonary mortality. Pollutants can enter the human body by inhalation, ingestion and dermal contact (Kampa and Castanas, 2008).

Measuring personal exposure to air pollution is an accurate way to determine human contact with pollution and estimates a person's actual pollution intake, rather than depending on pollution concentration measurements from central sites. Personal exposures can be measured by several methods, including personal monitoring, biological monitoring (both used to assess indoor exposure and ambient exposure), and environmental monitoring/modelling, which is used to assess ambient exposure (Zou et al., 2009). Modern sensors with high temporal resolution can estimate personal environmental exposures with high accuracy, but few studies have systematically compared multiple related pollutants measured concurrently from different personal sensors with those levels measured at the central site.

Pollutants commonly enter the body through the nasal cavity, and olfactory receptor cell dendrites are directly in contact with the environment (Brook et al., 2004, Calderón-Garcidueñas et al., 2002), hence both pinocytosis and neuronal transport are likely routes for pollutants to enter the central nervous system (CNS) (Calderón-Garcidueñas et al., 2002). For example, small sized particles can penetrate, diffuse and deposit in the respiratory tract, then directly translocate in the brain (Guxens and Sunyer, 2012, Morawska et al., 2008).

Studies by Block et al. (2004) and Hartz et al. (2008) on ultrafine particles emitted from diesel exhaust, and a study by Calderón-Garcidueñas et al. (2007) on chronic exposure to ambient air pollution including particulate matter, provide evidence of the effect of these pollutants on the blood-brain barrier function, which in turn contributes to Alzheimer's and Parkinson's diseases.

1.1 Research Aims and Objectives

The overall aims of this research are to characterize inhaled exposure to a mixture of pollutants including $PM_{2.5}$, BC, and UFP, that are typically encountered in Birmingham, the UK's 2nd largest city, and compare them with alternative surrogate exposure metrics (i.e. personal exposure, indoors at home, and central sites levels). It also aims to assess short-term personal exposure to air pollution and its effect on cognitive performance.

The three pollutants are defined as follows:

BC: *"an aerosol comprised of fine particulate matter that is produced from the incomplete combustion of fossil fuels or organic matter"* (Evans et al., 2017).

$PM_{2.5}$: *"Mass concentration of particles with an aerodynamic diameter less than or equal to a nominal 2.5 micrometers"* (Morawska et al., 2004).

UFP: *"particles with diameter less than 100 nm"* (Kumar et al., 2014).

The outcomes of this thesis will add valuable information to epidemiological studies, and source apportionment (i.e. identifying pollution sources and measurements of their contribution to pollution levels (Belis et al., 2014)). Furthermore, the research outcomes can be used by decision makers, to include air pollution in risk assessment, to set up and assign hazardous pollutants which most contribute to personal exposure for risk management, and control potential severe exposures (Adams et al., 2009).

It will add new information for the cognitive psychology field, and to epidemiology. It will help scientists to address the problems that may contribute to cognitive decline, hence finding ways to prevent, delay or mitigate cognitive problems, such as types of Dementia (e.g. Alzheimer, vascular dementia), and to decrease the cost and mitigate the burden spent on care and health sectors (Dougherty and Halliday, 2015).

1.2 Thesis structure

Chapters 2 to 6 of the thesis are organized according to the aims and objectives of the two cohort studies. Chapters 2 to 5 are related to the first cohort study, which uses novel sensors to assess human exposure to airborne pollutants. Then, chapter 6 is related to the second cohort study, which describes the assessment of the effect of short-term exposure to air pollution on cognitive performance. Chapter 7 presents the

overall conclusions of both cohort studies, and finally, chapter 8 gives some suggestions for future directions of research in the field.

CHAPTER 2: LITERATURE REVIEW

Some parts of this chapter are taken from Shehab. et al. (n.d.) review "Correlation between short and long-term exposure to air pollution and cognitive performance in adults and elderly: A systematic review", *and from Shehab and Pope paper "Effects of short-term exposure to particulate matter on cognitive performance"*

Ambient air pollution is one of the major contributors of morbidity and mortality in the modern world, with well-documented short- and long-term health effects (Brunekreef and Holgate, 2002). Exposure to air pollution is defined as "*the intersection in time and space of a concentration of pollution in the air and the presence of a human being*" (NRC 1991; Ott 1995). There are terms to define the time of exposure: acute, subacute, chronic and sub-chronic, the pollutant innate toxicity remains the same during the exposure at all times. However, the toxicity impact of personal exposure increases with the increase of time of exposure at lower concentrations (Connell et al., 2016). Hence, a pollutant concentration or dose, and the duration of exposure time are the main factors in assessing the effect of the pollutant (Bunce and Remillard, 2003).

Some studies assessed the effect of long term exposure to low concentrations of air pollutants, and found that there is an adverse effect from long term personal exposure to these low concentrations (Olmo et al., 2011; Raaschou-Nielsen et al., 2013). Currently, an ELAPSE (Effects of Low-Level Air Pollution: A Study in Europe) project is ongoing to investigate the effect of long term exposure to low concentrations of $PM_{2.5}$, Black

Carbon, NO_2 and O_3 on morbidity and mortality; the project started in 2016 and will end in the middle of 2019, and they will publish their first paper at the start of 2018 (ELAPSE, 2017).

Pollutants can enter the human body through inhalation, ingestion and dermal absorption (Kampa and Castanas, 2008), affecting different organs and physiological systems, particularly the cardiorespiratory system (Donaldson et al., 2001, Kampa and Castanas, 2008). Most of the previous studies on air pollution focused on respiratory (Atkinson et al., 2014) and cardiovascular diseases (Brook et al., 2010). However, air pollutants have a role in the pathology of neurodegenerative disorders; for instance metals (Jomova et al., 2010), which are emitted from many industrial activities e.g. cadmium, lead and mercury (World Health Organization, 2007), and particulate matters (Block et al., 2004, Calderón-Garcidueñas et al., 2007, Hartz et al., 2008) Thus it is logical to hypothesise that air pollution may have negative neurological consequences (Sanderson et al., 2014).The assessment of the impact of exposure to air pollution on cognition is, however, complex as cognitive function involves multiple domains, which include visual-spatial, executive function, verbal fluency, memory, attention, and orientation. These multiple domains cannot be measured by a single instrument. Whilst there are a growing number of reports on the neurotoxic properties of air pollution, these studies used a variety of assessment tools, rendering the interpretation of the findings difficult.

2.1 Use of Surrogate Sensors to Assess Human Exposure to Airborne Pollutants in Epidemiological Studies

Epidemiological studies have proven the adverse health effects caused by air pollution, including cardiopulmonary problems which lead to morbidity and mortality (Brook et al., 2004, Dockery et al., 1993, He et al., 2011, Jerrett et al., 2009, Peters et al., 2000, Pope et al., 2002).

However, these epidemiological studies can be inaccurate (Lokken et al., 2009, Shy et al., 1978). This is because they depend on inaccurate data in estimating human exposure to air pollution, taken for example from central outdoors monitors, which can provide measurement error results (Gamble, 1998, Gamble and Lewis, 1996, Ozkaynak et al., 2013, Zeger et al., 2000). Measurements error causes bias in regression coefficients (Carrothers and Evans, 2000); Brauer et al. (2002) also added *"Measurements error may affect the ability to observe a threshold level, should one exist"*.

Although several studies on exposure to particulate matter support the use of fixed central site monitors as a surrogate for personal exposure (Brunekreef et al., 2005, Janssen et al., 2005, Kim, 2002), studies on the association between personal exposure to UFP and their measurements at central sites are highly obscure and limited (Hoek et al., 2008, Pekkanen and Kulmala, 2004). Sioutas et al. (2005) concluded in their study that using central sites data may be inaccurate, because the issues related to exposure assessment of UFPs are complex (e.g. indoor sources, spatial variability, variability of

UFPs entering indoors from different outdoor sources, UFPs nature), and should be investigated before studying the health effects caused by them.

The association between central site concentration and people's indoor and outdoor houses can be different for $PM_{2.5}$ mass compared to UFP number concentration (Hoek et al., 2008).

According to Lokken et al. (2009), epidemiological studies depend on hospital admission data to assess human exposure to air pollution, which cannot assess the association between time of exposure to pollutants and the onset of acute symptoms (e.g. acute cardiovascular events), hence resulting in a misclassification impact.

Also, epidemiological studies depend on other inaccurate data, such as using central sites monitors as primary data sources to collect the data. These measure average pollutants concentrations from 24 hours to several days, which cannot determine acute and short-term personal exposure to these pollutants during daily activities and times spent in microenvironments (Delgado-Saborit, 2012). This can result in poor correlation between central site monitors and personal exposure, and hence cause serious bias in estimating the health effects caused by a pollutant (Brook et al., 2011).

Some studies used central sites as a surrogate for personal exposure, to find the effect of UFP, PM_{10} and $PM_{2.5}$ on lung functions. The results of these studies were inconsistent; where some studies found strong evidence that UFP has an adverse effect on lung function compared to PM_{10} and $PM_{2.5}$ results, others reported that UFP has similar or less effect than PM_{10} and $PM_{2.5}$. This heterogeneity in results can be due to exposure misclassification for UFP, which is greater than for PM_{10} and $PM_{2.5}$. Hence epidemiological studies for UFP can be inaccurate (de Hartog et al., 2010).

It is important to develop more accurate methods to assess human exposure to air pollution, such as using real time sensors (Delfino et al., 2008), in order to minimize misclassification impact (Jerrett et al., 2008, Sarnat et al., 2006).

Although many studies have assessed a single pollutant at personal exposure, few studies have assessed UFP at personal level. Some studies measured concentrations of multi pollutants concurrently at personal level, but they did not compare them systematically; furthermore, estimating their doses with short-term resolution at personal level has not been done before (Delgado-Saborit, 2012).

Delgado-Saborit (2012) states that more research is needed; including measuring UFP, $PM_{2.5}$, and BC concurrently at different locations (i.e. personal exposure, home, central site), and comparing these measurements with each other, to verify the degree of misclassification when depending on central site monitors as surrogate measures for personal exposures. Moreover, more research needs to be done on this area, including characterising the different types of personal exposure to airborne pollutants and considering detailed spatial and temporal resolution (Baxter et al., 2013, Delgado-Saborit, 2012).

Recent technology has produced a range of commercially available portable miniature size real time sensors (second to minute time resolution), with high temporal resolution that can estimate more accurate personal exposures, and distinguish between short-term or peak exposure and long-term averages (Chakrabarti et al., 2004). This can be useful in determining the effects that several activities (e.g. using gas stoves) and locations (e.g. time spent at home) have on personal exposure. In other words, determining time and location will help in recognizing the causality of exposure

pathways and exposure-related disease (Delgado-Saborit, 2012). This thesis will show how the results when using these sensors to measure concentrations of multi pollutants concurrently and systematically differ from those of previous studies.

2.2. Personal Exposure to Airborne Pollutants

People spend more of their time in residential indoors (Delgado-Saborit et al., 2011, Hinwood et al., 2003, Jenkins et al., 1992, Lai et al., 2004, Thatcher and Layton, 1995), and in the workplace (Delgado-Saborit et al., 2011, Harrison et al., 2002) than in other microenvironments. It has been found that people are exposed to pollutants from different sources in microenvironments and during activities, for example, people are exposed to higher levels of $PM_{2.5}$ from residential indoors, which can be associated with environmental tobacco smoke (ETS). Also, peak levels of carbon monoxide (CO) at personal exposure have been found to be associated with exposure to tobacco smoke, transportation, and cooking activities (Lai et al., 2004). Women who use gas stoves at home are at greater risk of respiratory problems (Jarvis et al., 1996). This thesis will investigate exposure to pollutants incurred during different activities and in various microenvironments. The following section shows two examples of these sources, and they will be explained in the following chapters, including their effects on cognitive performance.

2.2.1 Exposure to Pollutants from Candle Burning and Commuting

There are many sources of indoor and outdoor PM, that can be produced from different human activities that can contribute to exposure to air pollution, such as commuting, and candle burning, which will be explained below and in future chapters.

2.2.1.1 Exposure to Pollutants from Candle Burning

To understand how people are exposed to pollutants from candles, we need to know how candles produce pollutants, and what kind of pollutants are involved. Basically, all waxes are hydrocarbons; they consist of hydrogen and carbon atoms (National Candle Association). When a candle is first lit, the heat of the flame melts the wax around the wick, resulting in liquid wax. The combustion of liquid wax is transmitted through the wick pores by capillary flow, causing a flame that can exceed 1400 °C (Gritter et al., 2010).

The liquid wax is vaporized and turned into a hot gas by the flame's heat, and starts to separate the hydrocarbons into hydrogen and carbon molecules. These molecules are drawn up into the flame and react with oxygen from the air, creating light, water vapor, CO_2, and heat; this heat melts more wax and keeps the process of combustion going until the heat stops or until the fuel is finished.

This combustion stabilizes just a few minutes after lighting a candle; the flame may smoke or oscillate at first, but it will burn steadily in a droplet shape right after the combustion has stabilized. When there is very little or too much air, the flame may flare or oscillate (National Candle Association), and the flame will emit soot without full combustion (Buseck et al., 2012, National Candle Association).

The flame emitting soot will also produce elemental carbon particles (EC) (Buseck et al., 2012, Fine et al., 1999), and during the flaring process fine particles consisting mostly of

organic compounds are produced (Fine et al., 1999). Figures 1 and 2 illustrate the candle flame combustion process.

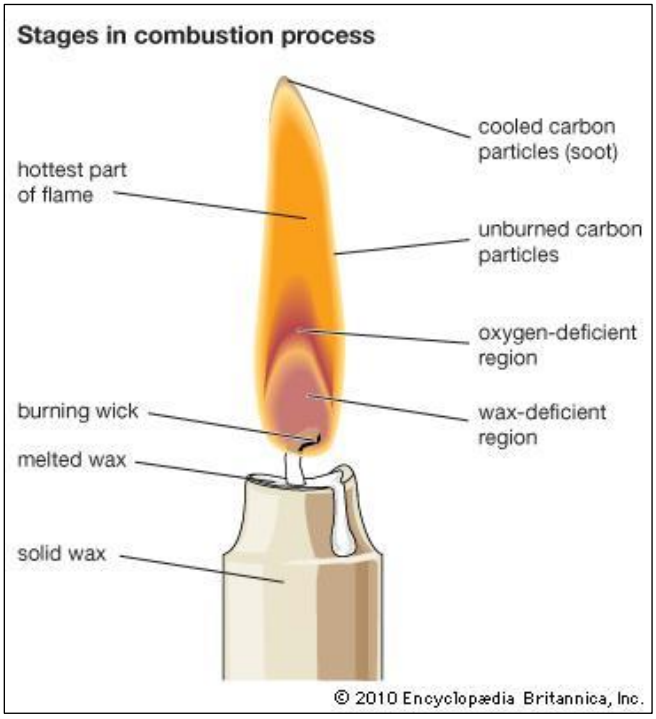

Figure 1: Stages in combustion process (Encyclopædia Britannica, 2010)

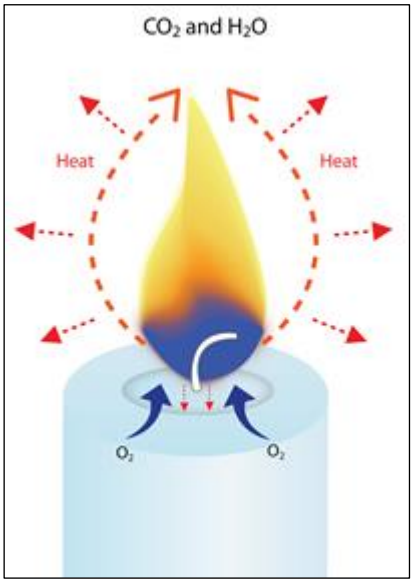

Figure 2: Stages in combustion process (National Candle Association)

Soot, which is emitted from the flame and disperses in air, can be inhaled and may get into the deepest areas of the lungs, the lower respiratory tract and alveoli; soot can precipitate on surfaces by one of the following factors:

- Hitting a surface,
- Passing through air conditioning filters and be dispersed in air,
- Soot may have enough mass to be dragged by gravity creating Black Soot Deposition (BSD) on carpets and other surfaces, or
- Surfaces that are electrically charged can attract the particles, such as plastic surfaces, and electricals like computers.

(Knight et al., 2001)

Combustion behaviour affects the rate of fine particles emissions (Fine et al., 1999), and the amount of soot is different depending on candle type; a steady and small flame emits a lower rate than a big oscillating flame that produces noticeable soot (Knight et al., 2001).

Particles like soot from burning candles can be reduced by cutting the wick; blowing out the flame increases the emissions (Knight et al., 2001). In an experiment by Fine et al. (1999), emissions from candle burning were reduced after each experiment by ventilating the room through opening windows.

2.2.1.2 Exposure to Pollutants from Commuting

Exposure to UFP from commuting is one of the daily contributors to personal exposure that are linked to health problems (Knibbs et al., 2011). Ambient air in urban

areas is also contaminated with pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), volatile organic compounds (VOCs) and other particulate matter (PM) (Deng et al., 2015).

PM is defined by Lippmann (2012): *"an ambient air criteria pollutant, is a complex mixture of chemical agents in particles ranging from nanometer-sized molecular clusters to dust particles too large to be aspirated into the lung airways (>10 μm in aerodynamic diameter)"*. Sources of PM emitted from different sources can affect both composition and concentration of ambient air in urban areas; these include mobile sources such as vehicles emitting exhaust fumes, and stationary sources such as food processing plants which produce smoke from smoke stacks. These two examples represent some of the major sources of urban outdoor air pollution; other pollutants from premises like restaurants, and residential activities like cooking and heating using coal and wood are also significant contributors to the urban outdoor air pollution levels (World Health Organisation).

The amount of pollutants emitted to the air depends on the activity that releases these pollutants, and this amount is expressed as an emission factor, for instance, kilograms of particulate matter released by each megagram of burning coal (Environmental Protection Agency, 2016), or the cubic micrometres emitted per vehicle driven distance (Deng et al., 2015). Emission factors depend on several variables, depending on the activity. For example, vehicle emission factors depend on road conditions (e.g. structure, slope), traffic conditions (e.g. traffic intensity, vehicle speed, type of fuel, type of vehicle,

age of fleet) (Colberg et al., 2005), and vehicle emission technology standards (Deng et al., 2015).

2.3 Effect of Air Pollution on Cognitive Performance

There is some evidence that small sized particles could penetrate, diffuse and deposit in the respiratory tract, then directly translocate in the brain (Guxens and Sunyer, 2012, Morawska et al., 2008), but the exact mechanism of the translocation is still unclear (Loane et al., 2013). It has been suggested that nanoparticles could reach the brain inside phagocytic cells travelling in the blood or lymph supply and traverse the brain-blood barrier (BBB) (Lucchini et al., 2012). Ultrafine particles containing metals and organic compounds might also enter the brain as free particles via the blood-brain barrier and deposit in different regions of the brain (Block and Calderon-Garciduenas, 2009).

Once air pollutants reach the brain, a combination of possible mechanisms might trigger the changes observed in the brain which are responsible for the decline of the cognition function associated with air pollution (Liu and Lewis, 2014). Oxidative stress produced by reactive oxygen species and free radicals (Kelly, 2003, Mills et al., 2009, Shih et al., 2007) may damage biomolecules such as lipids, proteins and DNA in the brain, contributing to brain tissue damage and leading to neurodegeneration (Block and Calderon-Garciduenas, 2009, Migliore and Coppedè, 2009, Sama et al., 2007, Veronesi et al., 2005). In addition, air pollution can cause a pro-inflammatory response in the cardiovascular and respiratory systems and the liver, leading to increased systemic inflammation, which in turn can induce neuroinflammation (Brockmeyer and D'Angiulli,

2016, Campbell, 2004, Kicinski et al., 2015, Mumaw et al., 2016, Wang et al., 2009). Neurotoxicological changes in humans exposed to air pollution have been observed. These include biomarkers of neuroinflammation**,** low concentrations of cytokines involved in neuroprotection, accumulation of β42 (Calderon-Garciduenas et al., 2012), microglial activation, stimulation of neuron apoptosis (Sama et al., 2007, Shih et al., 2007), reduction in neurotransmitter release (Kodavanti, 2005, Shih et al., 2007), changes in structural plasticity in the hippocampus (White et al., 2007) such as weakening synaptic plasticity (Li and Xin, 2013), reduced dendritic spine density in the hippocampus (Fonken et al., 2011), reduced brain volume (Chen et al., 2015, Wilker et al., 2015), and white matter lesions (Guxens and Sunyer, 2012). Cardiovascular changes might affect the vascular network in the brain, affecting blood coagulability and blood flow, both factors reducing the supply of oxygen and nutrients, and leading to hypoxia in the brain (Brockmeyer and D'Angiulli, 2016, Roher et al., 2012). In addition, changes in the vascular endothelium, such as disruption of the blood-brain barrier (Calderon-Garciduenas et al., 2002) produced by changes in microglia, might facilitate the entry of pollutants to the brain (Block and Calderon-Garciduenas, 2009). These effects are consistent with experimental data which shows that exposure to different sizes and composition of particulate matter produces and deposits misfolded protein aggregates (amyloid, alpha synuclein, hyperphosphorylated tau), oxidative stress, cell damage and death in susceptible neuronal populations (MohanKumar et al., 2008). All these changes may lead to cognition deficits, behavioural impairment and play a crucial role in the development of neurological disorders (Clark et al., 2010, Kicinski et al.,

2015), such as Alzheimer's Disease in the elderly (Calderón-Garcidueñas et al., 2004, Guxens and Sunyer, 2012).

2.3.1 Human Brain Cognition and Cognitive Domains

Dougherty and Halliday (2015) defined human cognition as *"the process of acquiring and comprehending knowledge through our senses and experiences".* Cognition manages our skills, including: learning, recalling and solving problems. For example, when the phone rings you hear the ring tone, and then react to answer it; this involves perception and decision making, motor-skills and language abilities, and social skills. The six cognitive domains of the brain that control all our activities are:

1- Visual-spatial: there is no unified definition for this domain, for instance, the definition used in the medical field is different from that used in education. This lack of unified definition and of boundaries may lead researchers to use visual-spatial terminology to talk about completely different aspects included in this domain (Williamson, 2008). It is described by neurobiologists as mental rotation, which is a complex cognitive process, backed by different neuropsychological activities, including shape perception, spatial reasoning and problem solving (Kucian et al., 2007). Psychologists on the other hand, subcategorize the process of visual-spatial cognition by distinguishing the ability to recognize objects from the ability to determine the spatial location of objects (Mazzocco et al., 2006).

Williamson (2008) identifies 8 different visual-spatial subcomponents, and their qualitative types of abilities, summarized in Table 1.

Table 1: visual-spatial subcomponents and their ability type

Visual-spatial subcomponent	Ability type
Visual-spatial mental manipulation	Structure objects into a meaningful whole and represent objects mentally
Visual-spatial organization	Distinguish objects from each other
Visual-spatial judgement	Judge the orientation of lines and angles
Visual-spatial relations and directionality	Use a small map to locate a target on a larger map
Visual-spatial memory	Understand the relationships among objects in space
Visuo-motor integration	Copy or reproduce a visually presented model using pencil and paper
Visual-perception processing	Differentiate and identify parts of a visual stimulus and recognize objects
Visual-spatial reconstruction	Solve and reconstruct spatial configuration problems

2- Executive Function: defined by Humphreys et al. (2012) as *"the ability to find rules in a sequence of stimuli and to apply them, and to switch mentally when the rules change"*. Psychologists and neuroscientists explain the brain processes by using the concept of executive system, these processes are responsible for: rule acquisition, initiating correct actions and preventing wrong actions, choosing relevant sensory information, planning, abstract thinking, and cognitive flexibility (Dougherty and Halliday, 2015).

3- Vebal Fluency: Dougherty and Halliday (2015) define it as *"the ability to generate language"* such as how fast can a person access to his vocabulary, or come up with language during a quick conversation. This can be different from person to person.

4- Memory: it is the ability to recognize items, remember things, and recall events from the past (Dougherty and Halliday, 2015, Humphreys et al., 2012). Forms of memory include:

- episodic memory, which implies recognition of items not explicitly memorised,
- long-term (delayed) and short-term (immediate) memory, to recall or recognise a list of items or events (Dougherty and Halliday, 2015, Humphreys et al., 2012),
- working memory, to store information at present for short time, to use it for a current task; it uses short-term memory for creating behaviours (e.g. directions leading to your room is in the short-term memory, tracking back and finding way out involves working memory) (Dougherty and Halliday, 2015),
- motor memory (muscle memory), is when the memory of action is learned (driving a car) and the activity is repeated, it will be attached to motor memory.

5- Attention: Like visual-spatial, there is no clear unified definition for attention, because many earlier studies consider attention as one single aspect, rather than a range of psychological concepts (Frey et al., 2015, Upton et al., 2012). Upton et al. (2012) used a broader definition to overcome the blurriness of attention's meaning, which is *"the process that controls the information that enters consciousness; this process has a limited capacity and can be consciously controlled".*

There are different types of attention, such as visual attention, which has two aspects, sustained attention, and selective attention. Sustained attention is the ability to concentrate on one particular task, and keep a consistent performance level over a continuous period of time, while ignoring distractors. Selective attention on the other

hand is the ability to select relevant targets while neglecting distractors (Eysenck and Keane, 2013, Ruff and Allen, 1996, Ruff et al., 1992, Stevens and Bavelier, 2012).

6- Orientation: it is people's consciousness of their time, place, and location (Dougherty and Halliday, 2015).

2.3.2 Studies on The Effect of Air Pollution on Cognitive Performance

A systematic search was done using PubMed, Web of Science, BioOne, ScienceDirect and Bioline, from the period 1960 to mid-2017. Twenty-four studies were found on the correlation between exposure to air pollution and cognitive performance, all having the same criteria: papers in English, healthy subjects, non-occupationally exposed, non-smokers, adults and elderly only. Twenty-four studies were found. Seven studies presented results on effects of short-term exposure to pollutants on cognitive performance (Bos et al., 2013, Chuwers et al., 1995, Driessen et al., 2012, Fiedler et al., 2008, Harbin et al., 1988, Leach and Almond, 1999), and seventeen on effects of long-term exposure to air pollution (Ailshire and Clarke, 2015, Ailshire and Crimmins, 2014, Chen and Schwartz, 2009, Gatto et al., 2014, Loop et al., 2013, Loop et al., 2015, Power et al., 2011, Ranft et al., 2009, Reed et al., 2014, Sánchez-Rodríguez et al., 2006, Schikowski et al., 2015, Sun and Gu, 2008, Tallon et al., 2017, Tonne et al., 2014, Wellenius et al., 2012, Weuve et al., 2012, Zeng Y, 2010, Zijlema et al., 2017). The main studies outcomes and the characteristics of short-term effects of air pollutants on cognitive performance are shown in Table 2 and Table 3. The characteristics of the long-term studies are shown in Table 1 Appendix 1.

Table 2: Main studies outcomes of short-term effects of air pollutants on cognitive performance

Pollutant	References	Aims and objectives	Tests used and purpose	Results	Limitations
Nanoparticles (PM, PNC, NO_2, NO, CO, THC)	(Driessen et al., 2012)	Investigation of the effect of nanoparticles from diesel exposure on cognitive function	- Adult Memory Information Processing Battery (AMIPB) task: assess information processing speed. - 15-word memory task: assess memory.	Exposure to diesel exhaust does not affect cognitive performance	- Did not consider confounding factors. - Subjects noticed absence of diesel exposure during non-exposure conditions (sham condition). - Low sample size
Ultrafine particulate matters (UFP)	(Bos et al., 2013)	Assess effect of UFP exposure on cognitive performance, inflammation, and neuroinflammation during aerobic training	- Stroop Color Word test: assess response-inhibition and selective attention (parts of executive function). - Operation Span test: assess working memory. - Psychomotor Vigilance Test (PVT): measures sustained attention and reaction time.	Exposure to PM has negative effect on cognitive performance in terms of executive function. No effect was found from Operation Span and PVT tests results	- Did not consider confounding factors. - Subjects aware they are exposed to the pollutant when taking the test. - Significant age difference between exposed group and control group. - Low sample size
Carbon monoxide (CO)	(Amitai et al., 1998)	Assess effect of low levels of CO on higher cognitive function	- Wechsler Memory Scale for adults: assess short-term and long-term semantic and figural memory. - Digit symbol: assess visuomotor coordination.	- CO associated with cognitive impairment in memory, new learning ability, attention and concentration, tracking skills, visuomotor skills, abstract thinking, visuospatial planning and processing; but statistically insignificant. - No effect appears from Rey Auditory verbal learning test	- Includes smokers: 13% of exposed group, 17% of control group. - Did not consider confounding factors. - Subjects aware they are exposed to

			- Block design: assess visuospatial organization and constructional skills. - Digit span forward and backward: assess immediate auditory memory, attention and concentration. - Trial-Making Test parts A and B: assess spatial planning and psychomotor abilities. - Rey Auditory verbal learning test: assess verbal memory and learning ability.		the pollutant when taking the test.
	(Harbin et al., 1988)	Assess effect of CO at low levels on neurophysiological function	- Visual Oddball task: Measures auditory attention, and attention capacity. - reaction time task: Measures motor control.	CO has no effect on cognitive impairment	- Did not consider confounding factors, except alcohol consumption and other substance abuse (i.e. drugs). - Subjects aware they are exposed to the pollutant when taking the test.
Hydrogen Sulphide (H_2S)	(Fiedler et al., 2008)	Assess effect of H_2S on symptoms, and sensory and cognitive performance	- Simple Reaction Time (SRT), and Continuous Performance Test (CPT): assess visuomotor speed. - Finger tapping: assess Motor speed.	H_2S has no effect on cognitive performance	- Did not consider confounding factors. - Subjects aware they are exposed to the pollutant when taking the test.

			- Symbol-Digit Substitution (SDS): assess perceptual-motor functioning, motor persistence, sustained attention, response speed, visuomotor coordination. - Auditory Verbal Learning Test (AVLT): assess verbal recall		- did not include a control exposure.
Ambient air, oxygen and nitrox mixture	(Leach and Almond, 1999)	Determine effect on cognitive performance from ambient air, oxygen, and nitrox mixture at different altitudes	- Grammatical reasoning test: analytic cognitive function. - Mathematical reasoning test: analytic cognitive function.	There is a slight positive improvement effect on grammatical reasoning for nitrox; and on mathematical reasoning for all gases	- Did not consider confounding factors. - Low sample size - Subjects aware they are exposed to the pollutant when taking the test.
Methanol vapour	(Chuwers et al., 1995)	Assess effect of methanol vapour at low levels on neurobehavioral performance	- 2 and 7: measures cerebral dysfunction. - Stroop: assess executive function. - Symbol-Digit Substitution (SDS): assess perceptual-motor functioning, motor persistence, sustained attention, response speed, visuomotor coordination. - Stenberg memory task: *"Measures speed with which the memory store can be searched, independently of decision*	Methanol vapour has no significant effect on neurobehavioral performance	- Did not consider confounding factors related to cognitive performance. - some smokers included in the study. - some subjects may be aware they are exposed to the pollutant when taking the test. - Low sample size

			time and motor response time". - Vistech: assess visual ability. - Lanthony 15 Hue Desaturated Panel: *"Measure impairment of chromatic discrimination and reflects neural damage".* - P-300: Assess cognitive dysfunction.		

Table 3: Characteristics of studies

Study name	Location	**Sample size**	**Age**	**Study design**	**Exposure concentration**	**Exposure assessment methodology**
Bos et al., 2013	Brussels and Mol, Belgium	24 (9 men, 15 women)	Range: 28-39; Mean (urban): 28 ± 8; (rural): 39 ± 6	Experimental Case-control (pre- and post-exposure in rural/urban groups)	**Mean ultrafine particle number (UFP)** measured at: **Urban:** 7,244 ± 2,559 particles/cm^3 **Rural:** 5,625 ± 1,896 particles/cm^3	**Microenvironment Exposure:** Average particle number concentration in the size range 0.02-1 µm was measured on the athletic tracks using a TSI-P-TRAK UFP counter.
Amitai et al., 1998	Jerusalem, Israel	92 (29 men, 63 women)	45 exposed: mean: 21.8 47 controls: mean: 22.2	Experimental Case-control design (exposed and control groups matched for age and sex)	**CO:** range: 17-100 ppm; mean: 61 ± 24 ppm **Venous blood carboxyhemoglobin (HbCO)**: range: 0.01-0.11; mean: 0.04 ± 0.03	**Microenvironment Exposure:** Presence/absence of residential kerosene stoves in dorms **Biomarker monitoring:** Presence of HbCO levels in blood
Harbin et al., 1988	Durham, USA	55 men (33 young and 22 elderly)	Young men (18-28; mean: 22.8) Elderly men (60-86; mean: 68.7)	Experimental Blinded crossover design (pre- and post-exposure of CO/air mixture)	**CO mixture:** 200ppm (1 h) and 50ppm (2 h) **Control:** air (3 h)	**Controlled exposure:** Subjects exposed to CO in an acoustically isolated experimental chamber. CO concentrations inside the chamber were measured with a Beckman infrared CO analyser. **Biomarker monitoring:** Presence of HbCO levels in blood
Fiedler et al., 2008	New Jersey, USA	74 (39 men, 35 women)	Mean: 24.7 ± 4.2	Experimental Double-blinded crossover design	**H_2S:** 0.05, 0.5, and 5 ppm	**Controlled exposure:** Subjects exposed to 5, 0.5 and 0.05 ppm of H_2S concentrations for 2 hours in a controlled environment chamber. Exposures were completed in separate exposure sessions conducted in random order over three consecutive weeks

Leach and Almond, 1999	Nepal	3 men (climbers)	30, 34 and 39 years	Experimental Case-control (Measured at 0, 610 and 5,332 metres of altitude)	**Mixture 1**: air **Mixture 2:** 100% oxygen **Mixture 3:** 60:40 nitrox (60% O_2 40% N_2)	**Controlled exposure:** Gas provided to participant via closed-circuit re-breathing apparatus
Chuwers et al., 1995	San Francisco, USA	26 (15 men, 11 women)	Mean: 35.7 ± 6.8	Experimental Double-blinded crossover design	**Methanol vapour**: 200 ppm for 4 hours **Control**: water vapour for 4 hours	**Controlled exposure:** Subjects exposed to methanol in a stainless-steel experimental chamber. Methanol concentrations inside the chamber were measured on real time with a Miran infrared spectrophotometer. Concentrations were also determined using Tedlar bags followed by gas chromatography.
Driessen et al., 2012	Heerlen, The Netherlands	12 (10 men, 2 women)	Range: 19-26 Mean: 21.5 ± 2.15	Experimental blinded randomised crossover design (pre- and post-exposure of engine exhaust/filtered air)	Nanoparticulate matter and gases from diesel engine exhaust. **PM** = 101± 31 µg/m^3 **Particle number** = 82,756 ± 8,330 #/m^3 **Median size** = 105± 2 nm **NO_2** = 79 ± 21 ppb **NO** = 157 ± 39 ppb **CO** = 119 ± 63 ppb **Total hydrocarbons** = 73 ± 15 µg/m^3	**Controlled exposure:** Subjects exposed to 10% of diesel engine exhaust mixed with air at steady-state concentration in a controlled environment chamber.

2.3.2.1 Cognitive Domains Assessments

Cognitive domains can be assessed using different cognitive tests. In earlier years, oral and written tests were used to assess cognitive performance; in recent years many computerized test batteries have been developed to assess different domains of cognition (Bolla, 1991).

All the studies included in section 2.4.2 used estimation tests to investigate if exposure to air pollutants may affect the cognitive performance of adults and older adults. However, there is a large range of cognitive performance tests used, which makes comparison between study results difficult, as there is no unified and accepted instrument that measures cognitive performance (Letz, 1991). On the other hand, although most of the studies have used different cognitive performance tests, most of the domains tested in the literature are common and include characteristics such as attention, executive function, memory, praxis and action. Indeed, memory is included in most of the studies that assess the effect of air pollution on cognition, although different types of memory have been tested in these studies, e.g. working memory, immediate memory, delayed memory or semantic memory.

2.3.2.2 Characterization of Short-term Exposures

The studies that assessed the effects of short-term exposure to air pollutant on cognitive performance characterised exposure to pollutants, either using controlled exposures (generally in chambers), microenvironment exposure or biomarker monitoring. The

different exposure assessment methodologies used in the short-term exposure studies are described in detail below.

- Controlled exposure: Controlled exposures might result from the exposure of subjects to a single pollutant or a mixture of air pollutants at known concentrations in an enclosed study chamber or from the inhalation of the pollutant mixture using a re-breathing apparatus. Leach and Almond (1999), who studied the effect of breathing different gases with increased altitude, requested that participants in the study inhaled air, oxygen or nitrox gas using a close-circuit re-breathing apparatus at three different altitudes (0 m, 610 m, and 5332 m). On the other hand, examples of controlled exposures using environmental chambers are several. For instance, Harbin et al. (1988) exposed subjects in an acoustically isolated experimental chamber to either 200 ppm of CO for 1 hour followed by approximately 2 hours exposure to 50 ppm of CO in air; or to normal air for the whole duration of the experiment (3 hours). All subjects were exposed to both the CO-mixture and the air control conditions in a blind randomised order, unknown to either the subjects or the experimental staff. CO concentrations inside the chamber were measured with a Beckman infrared CO analyser. Chuwers et al. (1995) exposed subjects to methanol in a stainless-steel experimental chamber. Methanol concentrations inside the chamber were measured in real time with a Miran infrared spectrophotometer. Concentrations were also determined using Tedlar bags followed by gas chromatography. The subjects performed the cognitive performance tests prior to exposure. They repeated three tests during the last 30 min of exposure and the remaining four tests after exposure was concluded.

Driessen et al. (2012) exposed subjects during one hour to 10% of diesel engine exhaust mixed with air at steady-state concentration and to filtered purified air (separated by a period of two to four days) in a blinded randomized cross-over study. Each subject was exposed in a transparent body-box, a sturdy plywood hermetically sealed chamber, allowing the subject to be exposed to different test atmospheres that were administered through a funnel placed in front of the subject's nose and mouth. Fiedler et al. (2008) used a controlled environment facility to expose subjects to 5, 0.5 and 0.05 ppm of H_2S concentrations for 2 hours in separate exposure sessions administered in random order over three consecutive weeks. Subjects completed the cognitive tests before and during the final hour of a two-hour exposure session.

- Microenvironment exposure: Microenvironments are defined as a location where air pollutants are homogeneously distributed across space for the whole duration of a subject exposure (Zou et al., 2009). Microenvironment sampling offers an effective means of estimating population exposures to air pollutants without the considerable logistical difficulties of personal sampling (Delgado-Saborit et al., 2009b). This was the approach followed by Amitai et al. (1998), who studied cognitive responses of two groups of young adults. The presence or absence of residential kerosene stoves for 1.5 to 2.5 hours prior to the test in small dorms during winter season defined the exposed and control groups. Concentrations of CO in the dorms were measured by portable carbon monoxide detectors during the administration of the cognitive performance tests. Similarly, Bos et al. (2013) measured the average particle number concentration in the size range 0.02-1 μm using a TSI-P-TRAK UFP counter on the athletic tracks where the

exposed and control groups were exercising in an urban and rural environment, respectively.

- Biomarker monitoring: Biological monitoring is a desirable alternative to air sampling for characterizing environmental exposures, because it accounts for all possible exposure routes, covers unexpected or accidental exposures and reflects inter-individual differences in uptake or genetic susceptibility (Lin et al., 2005). The use of urinary biomarkers has been widely adopted to assess environmental exposures in occupational (Forster et al., 2008, Rossbach et al., 2007) and general population (Aquilina et al., 2010b). Harbin et al. (1988) measured carboxyhaemoglobin (HbCO) spectrophotometrically from blood before and after of the exposure sessions in a controlled environment chamber. This method was also applied by Amitai et al. (1998), who measured HbCO levels in blood just after completion of the cognitive assessment tests to assess personal exposures of subjects exposed to CO from kerosene stoves.

2.3.2.3 Characterization of Cognitive Performance

A variety of cognitive performance tests was used in each study, to measure different primary cognitive domains and subdomains. Generally, tests measure multiple brain domains and subdomains. There are several cognitive tests that have been commonly used to assess the effect of short-term exposure to air pollutants on cognitive performance. More details in Table 3.

2.3.2.4 Studies Outcomes

Traffic and diesel exposure

A study conducted by Driessen et al. (2012) in a different experimental set-up in a body-box with mouthpiece exposure, also demonstrated functional changes in brain activity in the frontal cortex associated to diesel exhaust with a maximal effect 4 hours post exposure. However, acute effect exposure to diesel exhaust was not significantly associated with changes in cognitive function within the time-frame studied.

Bos et al. (2013) measured cognitive performance, brain-derived neurotrophic factor (BDNF) serum levels, which is considered to be a mediator of exercise-induced cognitive improvements, blood total and differential leukocyte counts, exhaled nitric oxide (eNO) levels in order to find the effect of traffic, using UFP as a marker on cognitive performance, during aerobic training in rural and urban areas. No significant effect of aerobic training in urban areas, where UFP were significantly higher, was found on the BDNF level in serum or in various cognitive tests, such as Operation Span and Psychomotor Vigilance Performance test. This is in contrast with improvements in reaction time associated with attention and analytical cognitive function observed in the rural group after exercising. In addition, levels of systemic inflammatory markers were increased in the urban group, especially blood leukocyte counts and neutrophil counts, as well as the levels of eNO, a marker of respiratory inflammation. Inflammation is considered one of the main mechanisms through which UFP exposure induces adverse effects on the brain. Therefore, the study concluded that exposure to high traffic-related

air pollution during aerobic training increases respiratory and systemic inflammation, and suggests an inhibition of the exercise induced cognitive improvements (Bos et al., 2013).

Carbon Monoxide (CO):

A study conducted by Amitai et al. (1998) found that subjects given short-term exposure to CO associated with kerosene stoves had significantly lower scores than the control group in the tests digit span forward, short-term and long-term semantic memory, digit symbol, block design, recall of figural memory, and Trial-Making part A. On the other hand, there were no significant differences between the exposed group and control groups in the other cognitive tests. Findings from the study (Amitai et al., 1998) indicate that CO emissions from kerosene stoves (a surrogate for short-term exposure to CO) are linked to dysfunctions in memory, new learning ability, attention and concentration, tracking skills, visuomotor skills, abstract thinking, visuospatial planning and processing. These results suggest that low-level short-term exposure to CO results in impairment of higher cognitive functions.

Harbin et al. (1988), reported no associations between short-term exposure to CO and cognitive performance in both young men and elderly men measured with the Visual oddball task, which measures attention and executive function, memory and praxis and action, and the Reaction Time Task, which measures attention, visual processing and reaction time.

Hydrogen Sulphide (H_2S):

Fiedler et al. (2008) found no significant dose-response effects on cognitive measures of performance, namely simple reaction test, continuous performance test, finger tapping test, symbol digit substitution test and auditory verbal learning test linked with short-term

exposure to H_2S. However, their study did not include a control exposure, so interpretation of their results is limited. The study showed no scientific evidence of an association between chronic or short-term exposure to H_2S exposure and impairment of cognitive function.

Oxygen and nitrox mixture:

Leach and Almond (1999), studied the association between ambient air, oxygen and nitrox mixture and cognitive performance on three healthy adults at three different altitude levels. Their results suggest that subjects that can adapt or acclimatise to different altitudes do not show a direct relationship between breathing different gases and cognitive functioning, measured as mathematical and grammatical reasoning (Leach and Almond, 1999).

Methanol vapour:

Chuwers et al. (1995) assessed the effect of four hours exposure to methanol vapour (200 ppm - like the industrial threshold limit value) on cognitive performance in healthy people. They found that there was no effect on neurobehavioral, visual and neurophysiological performances associated with acute exposure to methanol vapour at low concentrations.

2.3.2.5 Quality Assessment, Limitations, and Confounding Factors

All long-term exposure studies have considered socio-demographic characteristics, but not all of them considered the same characteristics. 11 out of 15 studies considered socio-economic status, but not all of them considered the same characteristics. 10

studies considered confounding factors that might have an effect on performing cognitive performance tests, but these confounders were insufficient and differ from study to study. Insufficiency in these confounders, in addition to neglecting some socio-demographic and socio-economic status increases the risk of bias in the results obtained.

There were some confounding factors not included in the study design, such as lead, which was a major component of traffic emissions in the era when leaded gasoline was predominantly used. Lead has an adverse effect on cognitive function, and older adults have been exposed to it in the past (Shih et al., 2006)**,** even at low concentrations (Weisskopf et al., 2007, Wright et al., 2003)**.** Lead concentration in the blood of older people was linked with long term exposure to leaded petrol exhaust from traffic, which might have affected cognitive performance (Weisskopf et al., 2007, Wright et al., 2003). But then again, another study found that the concentration of lead in the blood may not affect neurobehavioral performance (Krieg et al., 2005). In any case, lead as a confounding factor might have affected particularly those studies that have focused on the older population to study the relationship between exposure to traffic pollution and cognitive performance (Gatto et al., 2014, Loop et al., 2013, Power et al., 2011, Ranft et al., 2009, Sánchez-Rodríguez et al., 2006, Sun and Gu, 2008, Wellenius et al., 2012, Weuve et al., 2012b, Zeng et al., 2010). It is also the case that one of the main sources of lead in the urban environment was linked with traffic air pollution from gasoline vehicles (Harrison et al., 2003, Khillare et al., 2004, Zereini et al., 2005).

Moreover, although most of the studies controlled for socio-demographic and economic factors, the majority of these did not consider important confounding factors that may

affect the results of cognitive performance measurements, such as noise exposure, emotional status of the subjects, number of sleeping hours and sleeping problems, caffeine consumption (Smith et al., 2003), social life history and behavioural factors of the subjects (Dougherty and Halliday, 2015, Ellis et al., 2014, Engle-Friedman, 2014, Halperin, 2014).

Four short-term exposure studies include low sample sizes (Bos et al., 2013, Chuwers et al., 1995, Driessen et al., 2012, Leach and Almond, 1999), and hence low statistical power. But then again, these studies have included direct methods of exposure assessment, therefore reducing considerably the uncertainty associated to the exposure assessment.

In addition to the confounding factors, another source of bias that might affect the robustness of the results in epidemiological studies is the exposure assessment to air pollution. All the studies that have considered the effects of long-term exposure to air pollutants on cognition have estimated the exposure to airborne pollution by using different modelling approaches, spanning from proximity models, land use regression models, to others less popular such as dispersion modelling or hybrid models. Modelling exposures is a less accurate method to characterise intake of pollutants by humans than direct measurements (e.g. personal exposure), tends to underestimate exposures and introduces larger bias in the exposure characterisation (Aquilina et al., 2010a, Delgado-Saborit et al., 2009b, Zou et al., 2009). On the other hand, studies that have assessed the effects of short-term exposure to air pollution on cognition have used direct methods to assess pollution exposures. These methods ranged from controlled and microenvironment exposures, where the concentrations of the pollutants are measured

by appropriate instrumentation, and biomarker monitoring. These methods are deemed to be more representative of the real concentrations of air pollutants that the subjects have been exposed to during the short-term experiments (Aquilina et al., 2010b, Delgado-Saborit et al., 2009a, Delgado-Saborit et al., 2011).

Another factor of consideration is the wide range of pollutants included in the different studies. Most of the studies focusing on cognitive effects from long-term exposure to air pollution have focused on different metrics of particulate matter, including black carbon, as well as ozone and nitrogen dioxide. Therefore, it is difficult to assess which of the pollutants is the one that affects cognitive performance the most, as each study assessed different types of pollutants, and only very few included several pollutants, thus allowing comparison of their strength of association. At the same time, the studies used different types of cognitive performance tests, and each test is associated with different cognitive attributes. This methodological heterogeneity does not allow clarity as to which air pollutant affects a specific cognition domain the most, or whether an effect exists overall. These highlighted discrepancies also make it difficult to compare between the different studies.

Moreover, since traffic pollution is a complex mixture of particulate matter of different chemical composition and gases, it is difficult to determine if the effect found in a particular study is associated with a specific pollutant or if the pollutant under study is acting as a surrogate of the whole mixture (Delgado-Saborit, 2012). Some studies have conducted multi-pollutant analysis (Chen and Schwartz, 2009, Gatto et al., 2014, Schikowski et al., 2015, Tonne et al., 2014). That is the case of Ranft et al. (2009), who focus on PM_{10}, whilst Power et al. (2011) and Wellenius et al. (2012) focus on BC only.

However, some other studies have used traffic as a surrogate of air pollution exposure, as to better represent the airborne pollution mixture found in urban environments, but losing information on specific pollutant contribution (Ranft et al., 2009, Sánchez-Rodríguez et al., 2006, Sun and Gu, 2008, Wellenius et al., 2012, Zeng et al., 2010).

2.4 Study design

The study consists of two different cohorts, the first one using a novel sensor to assess human exposure to airborne pollutants. This cohort of 40 healthy non-smokers adult subjects were recruited to conduct exposure measurement at the personal level, in microenvironments, and at central sites. The second cohort was used to determine short-term personal exposure to air pollution and its effect on cognitive performance, and was divided into two tests; one where 30 healthy non-smokers adult subjects were exposed to $PM_{2.5}$ from candle burning, and the other where 33 healthy non-smokers adult subjects were exposed to PM from commuting. The design for each study is explained in more detail in chapter 3 and chapter 6.

The study initially aimed to integrate the effect of air pollution on cognitive performance with the human exposure to air pollution cohort study, but because some subjects refused to be tested for cognitive performance, because they thought that doing so would add more duties to the first cohort study, the study was divided into two cohort studies instead.

The choice of the locations of houses for the study was based on a qualitative method, where houses either directly on main roads or away from main roads were chosen according to their location using a map. The study did not take into account the seasonal

effect, because of time limitations and the insufficient number of subjects, which led to insufficient data for each season.

2.4.1 Quality Assurance and quality control

For quality assurance and quality control purposes, the calibration and validation for the sensors used in a previous study are deployed here to ensure the accuracy and precision of the data, and that the data analysis is based on an excellent quality dataset (e.g. identifying outliers, negative values, and blank and 0 values, which were removed) (Okam, 2017).

2.4.2 Statistical approach

The statistical approach used in this research includes both parametric tests (i.e. t-test, ANOVA) and non-parametric tests (Mann-Whitney, Kruskal-Wallis). The Mann-Whitney test is used to compare two groups, and the Kruskal-Wallis test is equivalent to ANOVA, and is used to compare more than two groups. The t-test and ANOVA are used to compare the means between groups, whereas the Mann-Whitney and Kruskal-Wallis tests compare the medians between groups.

When a non-parametric test is used in the study, a parametric test is also performed to provide additional information for use in future studies, and the results of these parametric tests are provided in the appendices.

A regression analysis is also used to determine the relationship between variables; this is shown in chapter 6.

CHAPTER 3: ASSESSING MISCLASSIFICATION WHEN USING CENTRAL SITE AND HOME POLLUTION MONITORS AS SURROGATES FOR PERSONAL EXPOSURE

This project is part of a cohort study (Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures) funded by the Health Effects Institute (HEI), which is a non-profit corporation chartered in 1980 as an independent research organization to provide high-quality, impartial, and relevant science on the health effects of air pollution. This research will appear in the report "Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures", in which the researcher is a co-author, but in this thesis the researcher wrote all the content herself. Recruitment of subjects, sampling, preparation of equipment and sensors, data collection, data insertion, and data analysis were all done by the researcher of this thesis, unless stated otherwise in the text.

3.1 Introduction and Overview

Typically, air quality epidemiological studies depend on measurements conducted from fixed position monitors in central sites as a surrogate to assess human exposure to air pollution. However, these measurements can be inaccurate, because they do not measure the true human personal exposure. Many activities (e.g. cooking) and many microenvironments (e.g. kitchen) are missed through use of these fixed position

monitors. This is also the case when using fixed monitors at home, whether inside or outside the house, because they do not measure other activities (e.g. working, lighting candles in different indoors locations such as religious premises) and other microenvironments (e.g. offices and restaurants), located away from the house. Therefore, the central hypothesis of this chapter is measurements from fixed site monitors cannot be used as a surrogate for personal exposure

If this hypothesis turns out to be true, then epidemiological studies cannot rely on these fixed monitors to assess personal exposure to air pollution.

Three air pollutants were measured: black carbon (BC), particulate matter ($PM_{2.5}$), and ultrafine particles (UFP). They were measured using portable personal monitors, and at two static locations: within the cohort participants' homes, and at fixed site AURN monitoring stations situated in Birmingham. The AURN sites were the Tyburn background site (where all three pollutants were measured), Tyburn roadside (BC and $PM_{2.5}$), and Acocks Green ($PM_{2.5}$ only).

3.2 Aims and Objectives

To characterize the personal dose of three air pollutants: BC, $PM_{2.5}$, and UFP; to compare the measurements with alternative surrogate exposure metrics (indoor at home and central site levels). Comparison of the three different personal dose estimates allows for the assessment of the degree of misclassification between personal monitoring and the use of fixed location monitoring.

3.3 Materials and Methodology

3.3.1 Recruitment of Subjects and Sample Selection Criteria

The overall study criteria for recruiting subjects include healthy, non-smoking, non-occupationally exposed adults. Sampling was conducted in Birmingham by the researcher of this thesis. All the forms and questionnaires used in this study were given ethical approval by the Institute of Research and Development of the University of Birmingham (reference: ERN_12-0568). Recruitment was achieved in a number of ways: by sending letters to addresses obtained from databases of volunteers who participated in previous studies, posting an announcement on the my-bham portal website (a University of Birmingham online information hub), announcement leaflets distributed in the university, and by informing colleagues and friends. First, a screening questionnaire was completed by potential volunteers to choose the eligible subjects. Then they read the participant information sheet, and the eligible volunteers who replied after reading the participant information sheet were interviewed to give them information about the study and to explain to them in detail their role in the research, to ask if they have any further questions and to make sure that they understood everything before signing the consent form. After signing the consent form, participants chose a convenient time and date slot for them to start sampling. Sampling was conducted from 6 December 2014 to 25 March 2016; each subject was sampled for 24 hours, for 4 consecutive days.

Each subject was visited regularly by the researcher, after making prior arrangements with the subject to ensure they would be at home, to check the operation of the

sensors and that the forms were filled correctly, and to ask the subject if they had any issues or further questions.

Questionnaires and Forms

Recruitment forms and leaflets:

- Announcement leaflet: contained information about the project and provided contact information for interested volunteers
- Participant interest letter: enclosed with the announcement leaflet in an envelope to be sent to home addresses, and containing general brief information about the purpose of the project
- Announcement posters: were posted on announcement boards in the Geography, Earth, Environmental Sciences building, and in the main library
- Online announcement: posted on the my-bham portal website
- Participant information sheet: gave more information about the project and the participants' involvement after they responded to the announcements
- Screening questionnaire: to include potential subjects who met the study criteria, and exclude the ones who didn't
- Baseline questionnaire: to obtain more information about the potential subject's environment
- Consent form: agreement to everything described in the information sheet, to be signed by participant

Each subject was given a folder including the following forms during their sampling:

- Confirmation form: signed by Dr. Juana Mari Delgado Saborit as a project supervisor (Use of novel sensors to assess human exposure to airborne pollutants).

This form should always be carried by the subject to help them justify their situation in case somebody asked them about the instruments.

- Participant instruction sheet: included instructions about the sheets and instruments subjects are carrying
- Activity diary: to record and describe all activities done by the subject
- Location sheet for in transit locations: to record and describe all outdoor locations visited
- Location sheet for static locations: to record and describe all indoor locations visited
- Environmental tobacco smoke (ETS) questionnaire: to give information about smoking if they were exposed to second hand smoke
- Sampling questionnaire: to describe some activities that may affect or produce pollutants
- Withdrawal form: In case participant no longer wanted to proceed with the sampling
- Sensors and charger photos: to show the subject which charger belonged to which sensor

Other forms:

- Standard operating procedure (SOP), for:
- Subject screening and sampling visits
- Gravimetric determination of filters
- Operating the MicroAeth™
- Operating the MicroPEM
- Operating the Ultrafine particle sensor DiSCmini
- Downloading and checking the data from the ultrafine particle sensor DiSCmini

- Pollutants sampling forms
- Personal and home exposure sampling sheet
- Tyburn central site sampling Sheet for UFP
- Filter weighing chart

Forms are available in Appendix 2. All the forms and questionnaires mentioned were prepared by Delgado-Saborit (2014), except the Announcement leaflet, which was prepared by both the researcher and Delgado-Saborit (2014). The Announcement poster, sensor and charger photos, and SOP for Operating the Ultrafine particle sensor DiSCmini, were prepared by the researcher.

3.3.2 Instruments and Equipment

Particulate matter ($PM_{2.5}$): Concentrations of $PM_{2.5}$ were collected at the personal level and from indoors at home using the MicroPEM™v 2.7 monitor, from the RTI International research institute. It measures $PM_{2.5}$ particles (particles with diameters of less than 2.5 micrometers) in real time using a nephelometric optical bench, and it collects particles using the integrated Teflon filter (25mm). The monitor is light weight (<240 g), and small (6.5 x 9.5 x 4 cm), which makes it easy to carry during daily activities, and is also quiet. It operates for up to 48 hours on three AA batteries, and can also run on AC mode connected to the mains. The monitor has a limit detection of 5 µg/m³ and an operational concentration range of 5-10,000 µg/m³ (RTI International). An ionizing blower and an α-particle source (210Po) are used to reduce the effect of static electricity on the Teflon filters, before weighing them using a

Sartorius Model MC5 microbalance. More details on SOP for gravimetric determination of filters are given in Appendix 2, along with the weighing chart.

Black carbon (BC): Black carbon (BC) real time concentrations were measured using the MicroAeth^{TM} Model AE51 personal monitor, which operates for up to 24 hours on a single battery charge, and can be connected to the mains power using an adapter. It provides real time analysis by measuring the rate of change in absorption of transmitted light due to continuous collection of air sample deposits on a T60 filter (Teflon coated glass fiber). The measurement range is 0-1 mg/m^3 with resolution of 0.001 µg/m^3; the measurements time base can be set to 1, 10, 30, 60, or 300 seconds. In this study, it was set to 300 seconds. This portable personal monitor is small (117 mm L x 66 mm W x 38 mm D), and light weight (280 g) making it easy to carry around during daily activity. It can store 4MB in its internal flash memory that can be uploaded to microAethCOM PC software and saved on local drive (Air Monitors).

Ultrafine particles (UFP): Ultrafine particle numbers (UFP) were measured using the portable sensor testo DiSCmini, which is a suitably small size (9x18x3.5 cm), with time resolution of up to 1 second (1 Hz). The sensor detects particle sizes ranging from 10 – about 700 nm, and measures UFP counts with a diameter lying below 300 nm, while the concentration ranges from about 1000 to over 1,000,000 particles/m^3. The battery lasts up to 8 hours, and the data is recorded on a memory card that can be transferred to an external local drive using USB cable (testo, testo company, 2012).

Voice recorder: subjects were given a voice recorder to make it easier for them to record their daily activities, microenvironments visited and times, and to listen to the recorder later when completing the forms.

Instrument bag: sensors located at home were placed in a hard vanity case, lined on the inside with temperature resistant foam, to reduce noise, with small holes drilled to fit cables allowing the sensors to be charged while inside the closed case.

3.3.3 Sampling and Data Collection

All sensors used were already validated in preparation for another project, directly before this research, (Delgado-Saborit, 2014). Measurements were collected with time resolution according to each sensor: for the MicroAeth™ which measures BC, a 5 minutes time interval; for the microPEM which measures $PM_{2.5}$, 10 seconds; and for the DiSCmini sensor which measures UFP, a 1 second time interval. The timescales were then integrated to time intervals of 5 minutes (for $PM_{2.5}$ and UFP), 1 hour, and 24 hours for all pollutants. All sensors were set to be charged overnight to ensure full charging; sensors that were placed in a subject's home and in central sites were on charge for 24 hours; sensors used for personal exposure were on charge overnight in their bedroom, and once the subject arrived home they were charging in the living room. Subjects were provided with photos of the sensors and their chargers to indicate which charger belonged to which sensor (Appendix 2). Instructions were given to the subjects on the first sampling day and through regular visits during sampling days to ensure everything was going well. More details on SOP for subject screening and sampling visits are included in Appendix 2. Data were extracted from

all sensors after each subject sampling, and checked with the activity diary sheet. If there was a peak in the data which was not clarified in the activity sheet, the subject was called to provide exact information on that particular time where there was a peak in data. Details on sampling procedures are given in the SOP for participant visits in Appendix 2.

Concentrations of particulate matter ($PM_{2.5}$), black carbon (BC), and ultrafine particles (UFP) were collected for 40 subjects from three locations, indoors from subjects' houses, personal exposure (PE), and central sites (CS).

For $PM_{2.5}$, concentrations from central sites (Tyburn background, Tyburn roadside, and Acocks Green) were downloaded from the data archive of Department for Environment food and Rural affairs (DEFRA) - Data Archive website. Measurements were downloaded after each subject's sampling from both sensors and central site for the same period of time, and data from the sensors were transferred and saved to a local drive using a USB cable. Sensors were prepared for the next subject's sampling: for microPEM sensors this included checking flowrate, checking for battery voltage and changing them when needed, and replacing the filters. Teflon filters from the microPEM were weighed in a lab with controlled temperature, filters were conditioned for temperature for 24 hours in the lab, placed in Petri dishes and labeled with subject ID number. More details are shown in the SOP for the MicroPEM, in Appendix 2.

For BC, concentrations from central sites (Tyburn background, Tyburn roadside) were also downloaded from the DEFRA Air Quality - Data Archive website. Data were downloaded after each subject's sampling from both central sites and sensors, data

from the sensors were transferred and saved to a local drive using a USB cable, and sensors were prepared for the next subject's sampling.

Preparing MicroAeth™ sensors included checking for flowrate and changing filters. More details are provided in the SOP for the MicroAeth™ in Appendix 2.

For UFP, the DiscMini sensor was used to measure ultrafine particles at personal level, in subjects' houses, and placed in the Tyburn background central site. Data were downloaded after each subject's sampling, and DiscMini sensors were prepared for the next subject's sampling by cleaning the inlets, checking for voltage, and checking the flow rate using the HEPA filter. More details are shown in Appendix 2 regarding the SOP for the ultrafine particle sensor DiscMini, the SOP for downloading and checking the data from the ultrafine particle sensor DiscMini, the Sampling Sheet for UFP - Tyburn, and the Sensors Sampling Sheet - PE and subject's home.

3.3.4 Preparation of Pollutants Measurements

Before analysing the data for each pollutant, concentrations measured by each sensor were corrected, to reduce the bias in the baseline that occurs from voltage variations, and correct the negative values measured which occur when the sensor's voltage drops. For UFP, data were corrected using Fierz method and equation (Fierz et al., 2008, Fierz et al., 2011); data measured were corrected by applying the validation correction factor corresponding to each DiSCmini, to calculate the corrected UFP concentration measured by the DiSCmini. For BC, Optimized Noise-Reduction Algorithm (ONA) software was used to reduce noise in real-time BC data

(Environmental Protection Agency), then the data were corrected using the Apte method (Apte et al., 2011).

As for $PM_{2.5}$, some negative measurements were noticed, due to the drop in the sensor voltage; to correct this, the baseline was dragged to zero by adding a number equal to the drop of the baseline; by raising the baseline all the concentrations will rise accordingly, after correcting the baseline. Concentrations measured by the sensor were compared with the concentration measured by the inside filters using an equation (i.e. calculating the gravimetric concentration using the small filter inside the sensor and comparing the gravimetric concentration to the concentration reported by the sensor), then validation correction factors corresponding to each MicroPEM sensor were applied using an equation. Correcting factors for all sensors are shown in more detail in Appendix 2.

3.3.5 Data Analysis

Minitab statistical software version 17.1.0 was used to conduct the following analysis:

A. Test of normality:

- Statistical analysis for pollutant (i.e. BC, $PM_{2.5}$, UFP), data normality in the different sites at 5 minutes (H, PE), 1-hour, and 24 hours' time intervals (H, PE, CS's).

B. Compare between pollutant (i.e. BC, $PM_{2.5}$, UFP) concentration in different sites, to assess the degree of misclassification

- Comparison between pollutant (i.e. BC, $PM_{2.5}$, UFP) concentration in different sites at 5 minutes (H, PE), 1-hour, and 24 hours' time intervals (H, PE, CS's).

3.4 Results

3.4.1 Recruitment of Subjects:

- There were high response levels from volunteers using gas and living away from traffic, however the response from those using electric stoves and living near traffic was very low, which necessitated a further recruitment drive to look for more volunteers in this category, and prolonged the overall subject recruitment time.
- There was a high response from the announcement through the my-bham website, which makes it a good way to find more subjects.

3.4.2 Statistical and Descriptive Results

Table 4 shows the number of volunteer responses for each recruitment method. Table 5 summarizes the descriptive analysis for each pollutant, from the three locations, statistical outputs including p-values are shown in Appendix 3.

Table 4: Volunteers response according to recruitment method

Method	Number of announcements sent	Number of respondents*	Potential subjects*	Subjects meet criteria-	Recruited*
Mass mailing	1500 letters	28	13	3	3
Announcement leaflet in the University	2 leaflets	47	26	23	9
My bham website announcement	2 times	92	57	54	15
Through colleagues	N/A	19	11	11	11

Volunteer's friends and colleagues	N/A	8	5	5	2

*Number of respondents are the subjects who responded to different announcements, and were sent a screening questionnaire and consent form to be completed and returned

*Potential subjects are the number of volunteers who completed screening questionnaire and sent them back

*Recruited are the subjects who agreed to participate to the project

- Some of the subjects who met the criteria did not reply to their e-mails.

Subjects who met the criteria but responded after the recruitment was completed were sent an e-mail informing them of the completion of recruitment

Table 5: Concentrations of BC (µg/m³), $PM_{2.5}$ (µg/m³), and UFP (#/cc), from personal exposure (PE), home, and central sites (CS's)

Pollutant	Location	Median	Min	Max	95ile	5ile
BC*	**5 minutes**					
	Home	1.1	0.0	400.3	4.6	0.8
	PE	1.1	0.0	1,284.2	6.4	0.0
$PM_{2.5}$*	Home	4.6	0.1	1,868	39.7	3.2
	PE	6.1	0.0	2,443	36.2	1.2
UFP*	Home	2,035	20.7	856,355.8	32,330.8	1,480.5
	PE	1,839.6	0.0	550,345	19,330.8	1,708.4
BC	**1 hour**					
	Home	1.1	0.0	172.2	4.8	0.2
	PE	1.2	0.0	120.2	6.7	0.0
	Tyburn background	0.9	0.1	12.2	3.2	0.2
	Tyburn roadside	1.9	0.1	15.3	6.5	0.2
$PM_{2.5}$	Home	4.6	0.0	1,276	41.8	3.2
	PE	6.3	0.0	1,948	38.3	0.3
	Tyburn background	7.6	0.1	78	33.2	6.1
	Tyburn roadside	10	0.1	79	36.8	2.2
	Acocks Green	6.6	0.1	100	33.7	4.3
UFP	Home	2,081	22	460,427	34,287.9	530.4
	PE	1,965	23	165,986	20,117.6	737.8
	Tyburn background	930.5	50	16,159	4,949.8	297.6
BC	**24 hours**					
	Home	1.3	0.2	19.3	4.3	0.4
	PE	1.5	0.0	13	5.5	0.4
	Tyburn background	1	0.4	4.5	2.6	0.4
	Tyburn roadside	2.1	0.6	8	4.9	0.8
$PM_{2.5}$	Home	6	0.2	124	42.1	0.6
	PE	8.3	1.0	194	29.2	2.3

	Tyburn background	8	1.8	56.3	37.6	3.0
	Tyburn roadside	10.5	4.3	57.3	39	4.7
	Acocks Green	7.1	1.7	56.4	36.4	2.8
UFP	Home	4,443.5	250	53,238	21,362.3	580.9
	PE	3,802.5	405	29,101	16,476.4	1,630.3
	Tyburn background	911.2	486.1	7,358.3	4,903.4	521.7

3.4.3 Hypotheses:

- The hypothesis to test normality is that the data in the three sites are not normally distributed.

- The hypothesis for misclassification is that there are significant differences in data measurements from the three sites.

The statistical tests were used to test these hypotheses were: normality test to test normality, and compare the p-values. To test misclassification hypothesis, the t-test or Mann-Whitney test, ANOVA or Kruskal-Wallis tests were used. As mentioned in the literature review, the Mann-Whitney test is a non-parametric test, used to compare two groups, and the Kruskal-Wallis is also a non-parametric test equivalent to ANOVA; it is used to compare more than two groups. The t-test and ANOVA compare the means between groups, whereas the Mann-Whitney and Kruskal-Wallis compare medians between groups.

With the t-test or Mann-Whitney the null hypothesis is that the two means/medians are equal, the alternative they are not equal. If ANOVA or Kruskal-Wallis the null is all means/medians are equal, the alternative at least one is not equal to the others:

A- Normality hypothesis:

H0: the data in the sites is normally distributed.

H1: the data in the sites is not normally distributed.

B- Degree of misclassification hypothesis:

- For t-test or Mann-Whitney tests:

H0: Means/ medians are equal.

H1: Means/ medians are not equal

- For ANOVA or Kruskal-Wallis tests:

H0: All means/medians are equal

H1: At least one mean/ median is not equal to the others

When conducting ANOVA there are two types to perform, one where equal variance is assumed and one where equal variance is not assumed. The Levene test is for equal variance between groups being tested. If <0.05 we do not assume equal variance. If >=0.05 we assume equal variance (null hypothesis is variance between groups is equal). There is then the option in ANOVA to assume or not assume equal variance. This slightly alters the test statistics, but interpretation remains the same.

A: Normality results:

The statistical analyses for BC, $PM_{2.5}$, and UFP data normality at all locations (home, PE, CS's), at all time intervals, show that the p-value for all measurements <0.01, hence the null hypothesis is rejected. In other words, none of the results from measurement locations of BC, $PM_{2.5}$, and UFP at any of the time scales were normally distributed.

B: Degree of misclassification results:

With one exception, the results from all the tests (M-W test, Levene's test, and Kruskal-Wallis test) to assess the degree of misclassification between the three locations provided p-values of 0.000 for each pollutant. The exception was $PM_{2.5}$ at 24 hours, where the p-values were: Levene's test 0.703, while the Kruskal-Wallis test was 0.000

3.5 Discussion

All data for the three pollutants are not normally distributed. Although the data are not normally distributed, we can still use the t-test and ANOVA as the sample sizes are quite large for future studies that can be added to this research data (Chassan, 1979, Roscoe, 1975, Minitab, 2017). As the data are highly skewed, non-parametric tests (i.e. the Mann-Whitney for two groups and Kruskal-Wallis) were conducted; the the Mann-Whitney and Kruskal-Wallis compare medians between groups.

The results show that there is a difference between the three locations. The only result that is not statistically significant is the 24hr data for $PM_{2.5}$. The equal variance test is not significant for 24hr $PM_{2.5}$. Although the $PM_{2.5}$ data indicates there is no statistical difference between the means for Home, PE, Tyburn, Tyburn Roadside and Acocks Green (p-value 0.232), the test for median is statistically significant. This means there is no difference for the mean, but is for the median. This reflects the amount of skew in the data.

For BC, at 5 minutes time interval, the mean concentrations from PE are higher than Home. At the 1-hour time interval, concentrations from Tyburn roadside are the

highest, followed closely by PE, then Home, and Tyburn background. Similar values were found for the 24 hours' time interval, where concentrations from Tyburn roadside are the highest, followed closely by PE, then home, and Tyburn background.

For $PM_{2.5}$, at the 5 minutes time interval, concentrations from PE are higher than home. At the 1-hour time interval, concentrations from PE are the highest, followed by Tyburn roadside, home, Tyburn background, and Acocks Green. There is considerable overlap because of high variation in the PE and Home data. At the 24-hours' time interval, data indicates there is no statistical difference between the means for Home, PE, Tyburn, Tyburn Roadside and Acocks Green (p-value 0.232); however, the median is statistically significant, where it is highest for Tyburn roadside, then PE, Tyburn background, Acocks Green and Home.

For UFP, at the 5 minutes time interval, measurements from Home are higher than PE. At the 1-hour time interval, measurements are highest for Home, then PE, and Tyburn background. At the 24-hour time interval, measurements are highest for Home, then PE, and Tyburn background.

In conclusion, the degree of misclassifications is statistically significant for the three pollutants, between all locations, although the results for $PM_{2.5}$ at 24-hour time interval, show that the median is statistically different, but the mean is not statistically different for Home, PE, Tyburn, Tyburn Roadside and Acocks Green. We can conclude that the degree of misclassification is significant between the three locations, for the three pollutants.

The results provide evidence that the variances between the pollutants measurements from different locations are significant. This indicates the degree of misclassification is significant between most of the locations.

For BC, there is a significant difference between PE and home at the 5 minutes time interval, and between Tyburn roadside, home and Tyburn background at the 1-hour time interval, but not significant between Tyburn roadside and PE. For $PM_{2.5}$ there is a significant difference between PE and home at the 5 minutes time interval, and between all the other locations at the 1-hour time interval. However, when the measurements are integrated to 24-hours, the mean between all locations shows no significant differences, while the medians between all locations show significant differences. As for UFP measurements, the results show significant differences between the locations at all time intervals.

The findings suggest that epidemiological studies will be inaccurate, due to their dependence on central sites to assess personal exposure to air pollution (Brauer et al., 2002, Gamble, 1998, Gamble and Lewis, 1996, Hoek et al., 2008, Lokken et al., 2009, Pekkanen and Kulmala, 2004, Sioutas et al., 2005, Zeger et al., 2000) At the same time they contradict the studies which support the use of fixed central site monitors as a surrogate for personal exposure such as Brunekreef et al. (2005), Janssen et al. (2005), and Kim (2002).

The results support using personal exposure monitors instead of the central sites to assess the effect of air pollution on health. They suggest it would be useful to repeat the studies done before on the correlation between human health and air pollution which used central sites as a surrogate for personal exposure, using the personal

monitors. The new studies should be compared to the previous studies to assess the differences between the findings, and whether they support or contradict each other.

3.6 Conclusion

This is the first study that estimates personal environmental exposures using modern sensors with high temporal resolution and high accuracy, and systematically compares multiple related pollutants measured concurrently from different personal sensors with those levels measured at central sites. The findings conclude that using central sites to assess human exposure to air pollution is not accurate, and cannot be used as a surrogate for personal exposure. It provides clear evidence of the improved accuracy of using personal monitors instead of central sites in epidemiological studies.

CHAPTER 4: CHARACTERIZATION OF THE PROFILE OF THE POLLUTANT MIXTURE, AND CONTRIBUTION TO PERSONAL EXPOSURE ASSOCIATED WITH DIFFERENT ACTIVITIES AND MICROENVIRONMENTS

This project is part of a cohort study (Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures) funded by the Health Effects Institute (HEI), which is a non-profit corporation chartered in 1980 as an independent research organization to provide high-quality, impartial, and relevant science on the health effects of air pollution. This research will appear in the report "Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures", in which the researcher is a co-author, but in this thesis the researcher wrote all the content herself. Recruitment of subjects, sampling, preparation of equipment and sensors, data collection, data insertion, and data analysis were all done by the researcher of this thesis, unless stated otherwise in the text.

4.1 Introduction and Overview

Previous studies stated that people spend most of their time indoors, either at home (residential) (Delgado-Saborit et al., 2011, Hinwood et al., 2003, Jenkins et al., 1992, Lai et al., 2004, Thatcher and Layton, 1995) or at workplaces (Delgado-Saborit et al., 2011, Harrison et al., 2002). In these locations, they can be exposed to higher PM

associated with environmental tobacco smoke (ETS) from co-workers or in smoking households. It has also been found that higher levels of carbon monoxide (CO) at personal exposure are associated with exposure to ETS, transportation, and cooking (Lai et al., 2004).

In addition, commuting can be one of the major sources of personal exposure to pollutants, because the commuters are in direct and close contact with the different transport modes (e.g. car, bus, walk, train), and exposed to short-term peak pollutants concentrations during their commuting (Rivas et al., 2017a).

A study conducted by Gulliver and Briggs (2007) in Leicester – UK, showed that people were exposed to higher PM while walking than while driving cars.

There are several factors affecting personal exposure to pollutants during commuting, such as wind speed (i.e. pollutants concentrations decrease when the wind speed increases) (Adams et al., 2001; Kaur and Nieuwenhuijsen, 2009; Rivas et al., 2017b; Weichenthal et al., 2008), transport mode (Adams et al., 2001; de Nazelle et al., 2012; Kaur and Nieuwenhuijsen, 2009; Rivas et al., 2017b), route (Adams et al., 2001; Rivas et al., 2017b), traffic intensity (Kaur and Nieuwenhuijsen, 2009; Rivas et al., 2017b), traffic flow speed, time of day (Rivas et al., 2017b), temperature (Kaur and Nieuwenhuijsen, 2009; Weichenthal et al., 2008), and background concentrations (de Nazelle et al., 2012).

The purpose of this chapter is to characterize the profile of the pollutant mixture from the personal exposure monitor, in order to determine the key activities and microenvironments associated with the highest concentrations of BC, $PM_{2.5}$, and

UFP, and to determine the contribution of different activities and microenvironments to personal exposure of BC, $PM_{2.5}$, and UFP.

4.2 Characterization of the Profile of the Pollutant Mixture Associated with Activities Conducted and Microenvironments Visited by Subjects

4.2.1 Aims

To identify key activity and microenvironment associated with the highest concentration of BC, $PM_{2.5}$, and UFP. This section hypothesizes that activities and microenvironments related to transportation are associated with the highest concentrations of BC, $PM_{2.5}$, and UFP.

4.2.2 Methodology and Materials

The same methodology and data from Chapter 3 were used. The subjects' time/activity diary sheet was used to determine and define the activities conducted and the microenvironments visited by the subjects, and then the relevant activities and microenvironments were grouped into categories (Appendix 4, Table 1 and Table 2).

4.2.3 Data Analysis

The data analysis was conducted using data from personal exposure during activities and microenvironments at 5 minutes' time intervals, for 4 consecutive days, where the total exposure was calculated for the whole sampling period in order to:

a- Define and draw up a detailed list of activities of interest and list of microenvironments of interest

b- Integrate exposures during activity and microenvironment to calculate:

- arithmetic mean, standard deviation (SD), Median, percentile, quartile deviation (QD) minimum, maximum, and skewness.

SPSS version22 statistical software was used to conduct analyses for mean, median, standard deviation (SD), minimum, maximum, percentiles, and skewness. Microsoft Excel 2016 statistical software was used to conduct quartile deviation (QD).

4.2.4 Results

- Hypothesis:

Activities and microenvironments related to transportation are associated with the highest concentration of BC, $PM_{2.5}$, and UFP, these include travelling in vehicles, outdoors commuting for activities, and in vehicles for microenvironments.

All detailed activities done and detailed microenvironments visited by the 40 subjects were grouped into categories. All details and groups of activities and microenvironments are shown in Appendix 4. Appendix 4 provides a detailed breakdown of all activities conducted by the 40 subjects, as well as all microenvironments visited, grouped into categories each having a different code.

Table 6 shows the concentrations analysis results for the pollutants during activities done and microenvironments visited by the 40 subjects, from personal exposure, at 5

minutes' time intervals for 4 consecutive days, where the total exposure was calculated for the whole sampling period.

For each activity and microenvironment skewness was calculated and included in the table. Skewness is a measure of the data distribution's asymmetry; when the values cluster around the mean then the data is not skewed and is normally distributed, but if the values are clustered below the mean or above the mean then the data is skewed (below the mean is called positive skew, and above the mean is called negative skew).

Arithmetic mean (AM) and standard deviation (SD) are good measures if the data are not skewed; median and quartile deviation (QD) are good measures if the data are skewed, QD is the interquartile range divided by 2 (Q3 - Q1 / 2), also called semi-interquartile range. If the skewness for all sets of data in a table is less than 1 the AM and SD are used; if skewness for one or more sets of data in a table is greater than 1 the median and QD are used. Since skewness in all results is more than 1, median and QD are used. All other information is shown in Appendix 4 (mean, standard deviation, minimum, maximum, percentiles, and skewness), which provided only as an additional information, to be used in further studies that may done in the future.

Table 6: Personal exposure of BC (µg/m³), $PM_{2.5}$ (µg/m³), and UFP (#/cc) concentrations associated with different activities and microenvironments, at 5 minutes time interval

Code	Description	BC		$PM_{2.5}$		UFP	
		Median	QD	Median	QD	Median	QD
Activities							
1	Travelling in vehicles	2.6	6.1	8.6	11.2	3824.4	6910.5
2	Outdoors commuting	1.7	3.2	9.7	17.7	2109.7	4850.2
3	Other outdoor activities	2.1	3.5	8.9	13.0	2156.8	3393.1
4	Working	1.0	1.6	4.5	6.1	1915.8	3031.0
5	Indoor activities – light exercise	1.3	2.1	7.1	8.5	2276.6	4447.9
6	Indoor activities – medium exercise	1.6	2.6	7.8	10.0	3023.9	3988.5

7	Indoor activities – high exercise	1.3	1.7	7.5	9.0	1406.1	2593.0
8	Indoor activities – cooking	1.6	2.6	7.8	19.0	4961.5	24429.4
9	Indoors activities – rest	1.0	1.7	5.9	6.1	1489.4	2167.7
Microenvironments							
1	Indoors – home	1.0	1.8	6.1	6.7	1836.2	2855.8
2	Indoors – friends/ relative's homes	0.9	2.1	4.9	4.3	1728.6	1366.6
3	Indoors – kitchen	1.7	2.2	8.5	19.8	3940.2	24147.2
4	Indoors – office	1.0	1.5	4.3	5.5	1570.6	2139.7
5	Indoors – hospitality retailers	1.8	2.9	10.2	15.1	2298.8	4477.1
6	Indoors – others	0.6	3.8	10.9	7.7	1929.6	2529.5
7	Indoors – shopping areas	2.1	3.2	8.3	11.7	1747.2	6385.0
8	In vehicles	2.6	6.1	8.5	11.2	3791.1	6843.8
9	Outdoors – traffic areas	1.9	3.6	8.9	15.4	2397.0	5767.2
10	Outdoors – non-traffic areas	1.8	3.1	10.6	16.9	1854.0	2989.5
11	Hospital/ medical related	1.2	2.4	9.6	10.4	4000.6	23063.7
12	Indoors exercising	1.5	4.3	7.0	8.5	1283.5	1936.4

Results from the BC data show that the highest concentrations linked to activities are travelling in vehicles (2.6 µg/m³, 6.1), followed by other outdoors activities (e.g. in a park) (2.1 µg/m³, 3.5), and outdoors commuting (1.7 µg/m³, 3.2), while the lowest concentrations linked to activities are working (1.0 µg/m³, 1.6), and indoor activities - rest (i.e. sleeping, relaxing) (1.0 µg/m³, 1.7). The highest concentrations linked to microenvironments are in vehicles (e.g. car, train) (2.6 µg/m³, 6.1), followed by indoors shopping areas (2.1 µg/m³, 3.2), and outdoors traffic areas (1.9 µg/m³, 3.6) which is slightly lower, while the lowest concentrations linked to microenvironments are indoors - others (0.6 µg/m³, 3.8).

Results from the $PM_{2.5}$ data, shows that the highest concentrations linked to activities are outdoors commuting (9.7 µg/m³,17.7), followed by other outdoor activities (8.9 µg/m³, 13.0), and travelling in vehicles (8.6 µg/m³, 11.2) which is slightly lower, while the lowest concentrations linked to activities are working (4.5 µg/m³, 6.1). The highest concentrations linked to microenvironments are indoors - others (10.9 µg/m³, 7.7), followed by outdoors – non-traffic areas (10.6 µg/m³, 16.9), and indoors – hospitality

retailers (10.2 µg/m³, 15.1) which is slightly lower, while the lowest concentrations linked to microenvironment are indoors office (4.3 µg/m³, 5.5).

Results from the UFP data, show that the highest concentrations linked to activities are indoors activities – cooking (4,961.5 #/cc, 24,429.4), followed by travelling in vehicles (3,824.4 #/cc, 6,910.5), and indoors activities – medium exercise (3,023.9 #/cc, 3,988.5), while the lowest concentrations linked to activities is indoor activities – high exercise (1,406.1 #/cc, 2,593.0). The highest concentrations linked to microenvironments are hospital/ medical related (4,000.6 #/cc, 23,063.7), followed by indoors – kitchen (3,940.2 #/cc, 24147.2), and in vehicles (3,791.1 #/cc, 6,843.8), while the lowest concentrations linked to microenvironment are indoors exercising (1,283.5 #/cc, 1,936.4).

The results support the hypothesis in terms of activity, as the highest concentrations for the three pollutants was found to be during travelling in vehicles, although for the UFP they show that travelling in vehicles is the second highest activity after cooking. The microenvironment that showed the highest BC concentration is in vehicles, whereas for UFP in vehicles was found to be the third highest concentration. Non-traffic areas can also be affected by traffic (i.e. emission factors), where $PM_{2.5}$ showed the second highest concentration in this microenvironment. Vehicle emission factors are affected by road conditions including structure or slope, traffic conditions including traffic intensity, vehicle speed, type of fuel, type of vehicle and age of fleet (Colberg et al., 2005), and vehicle emission technology standards (Deng et al., 2015).

4.3 Contribution to Personal Exposure Associated with Different Activities and Microenvironments Pollutant Profile

4.3.1 Aim

To determine the contribution of different activities and microenvironments to personal exposure of BC, $PM_{2.5}$, and UFP. This chapter hypothesizes that activities and microenvironments related to residential indoors contribute the most to personal exposure.

4.3.2 Methodology and Materials

The same methodology and data from Chapter 3 were used. Each activity and microenvironment category was analyzed, using the data for personal exposure at 5 minute time intervals for 4 consecutive days.

4.3.3 Data analysis

Microsoft Excel 2016 statistical software was used to conduct the analysis for 40 subjects.

- Calculate the average contribution from activity A to personal exposure, assessed by the same approach used in the Harrison et al. (2009) project. This set out to optimize a personal exposure model based on microenvironment concentrations and time/activity diaries as a useful alternative technique for measuring exposure to volatile organic compounds (VOCs):

% exposure to Compound Z due to Activity A for subject I = $\frac{t_{ia} * X_{iaz}}{\sum_{a=1}^{A} t_{ia} * X_{iaz}} * 100$ *(equation1)*

where t_{ia} is the time spent doing activity A by subject i over the sampling period (4 days), X_{ia} is the concentration representative of activity A for subject i and T_i is the total sampling time for subject i over the sampling period (4 days).

- Produce a table showing the different contribution of activities by ID

- Calculate the total contribution from activity A to personal exposure for all the subjects in total, assessed by the same approach used in the Harrison et al. (2009) project:

% exposure to Compound Z due to Activity A = $\frac{\sum_{i=1}^{I} t_{ia} * X_{iaz}}{\sum_{i=1}^{A}\sum_{i=1}^{I} t_{ia} * X_{iaz}} * 100$ *(equation 2)*

- Conduct the same data analysis for microenvironments of interest as above.

4.3.4 Results

Tables 1 to 6 in Appendix 5 provide a summary of all the data for the contribution to personal exposure for all the activities and microenvironments of the three pollutants, at 5 minute time intervals for 4 consecutive days; the total exposure was calculated for the whole sampling period for each of the 40 subjects, and for all subjects in total.

4.3.4.1 Contribution to Personal Exposure Associated with Different Activities and Microenvironments - BC Results

4.3.4.1.1 Activities Contribution to Personal Exposure of BC

The results presented in Table 1 in Appendix 5 show that indoor activities at rest (i.e. sleeping, relaxing) contribute the most to personal exposure for 25 subjects; contributions range between 27.4% (ID 28) and 78.185% (ID 32), as the amount of time spent on these activities was high.

4.3.4.1.2 Activities Contribution to All Subjects' Exposure in Total of BC

Figure 3 illustrates results presented in Table 1 in Appendix 5 for activities contribution to personal exposure of BC for all the 40 subjects in total, calculated from personal exposure data at 5 minutes' intervals for 4 consecutive days, where the total exposure was calculated for the whole sampling period. Results show that indoor activities at rest (i.e. sleeping, relaxing) contribute the most to personal exposure, with a percentage of 37.0%.

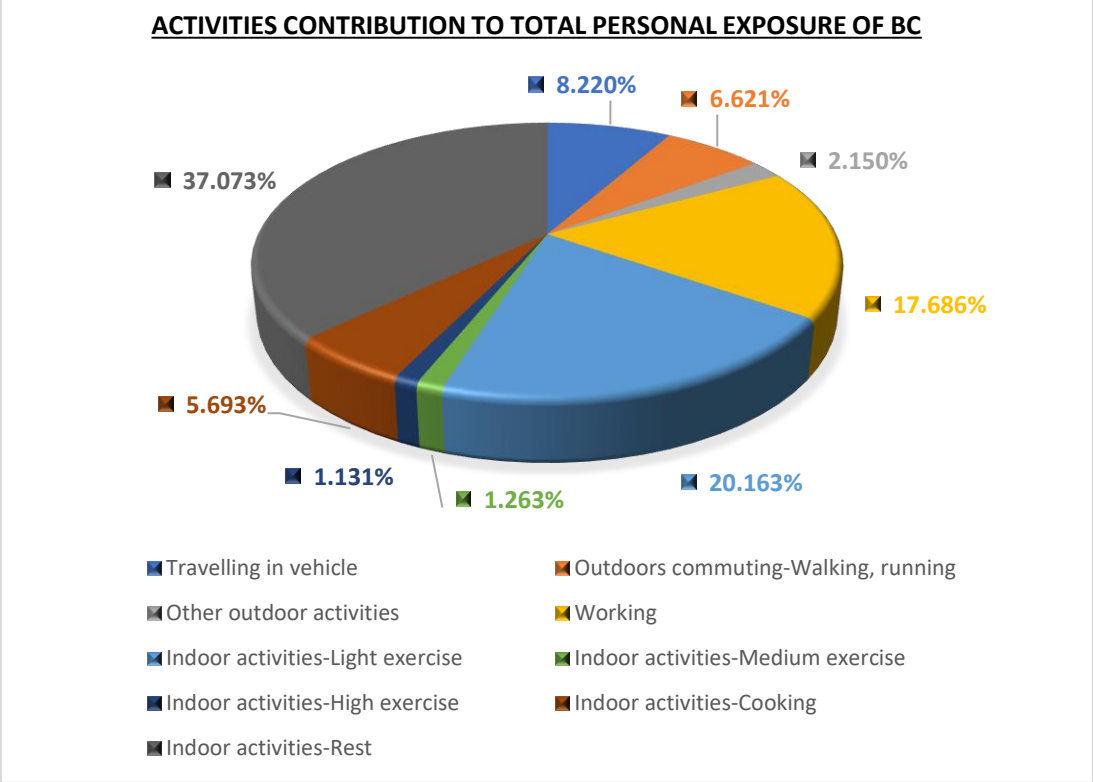

Figure 3: Total activity contribution to BC

4.3.4.1.3 Microenvironments Contribution to Personal Exposure of BC

Results from Table 2 in Appendix 5 show that indoors at home contributes the most to personal exposure for 38 subjects, with contributions ranging between 41.7% (ID 3) and 93.7% (ID 37).

4.3.4.1.4 Microenvironments Contribution to All Subjects' Exposure in Total of BC

Figure 4 illustrates results presented in Table 2 in Appendix 5 for the contribution of microenvironments to personal exposure of BC for all the 40 subjects in total, at 5

minutes' intervals for 4 consecutive days, where the total exposure was calculated for the whole sampling period. Results show that indoors at home contributes the most to personal exposure with percentage of 59.8%.

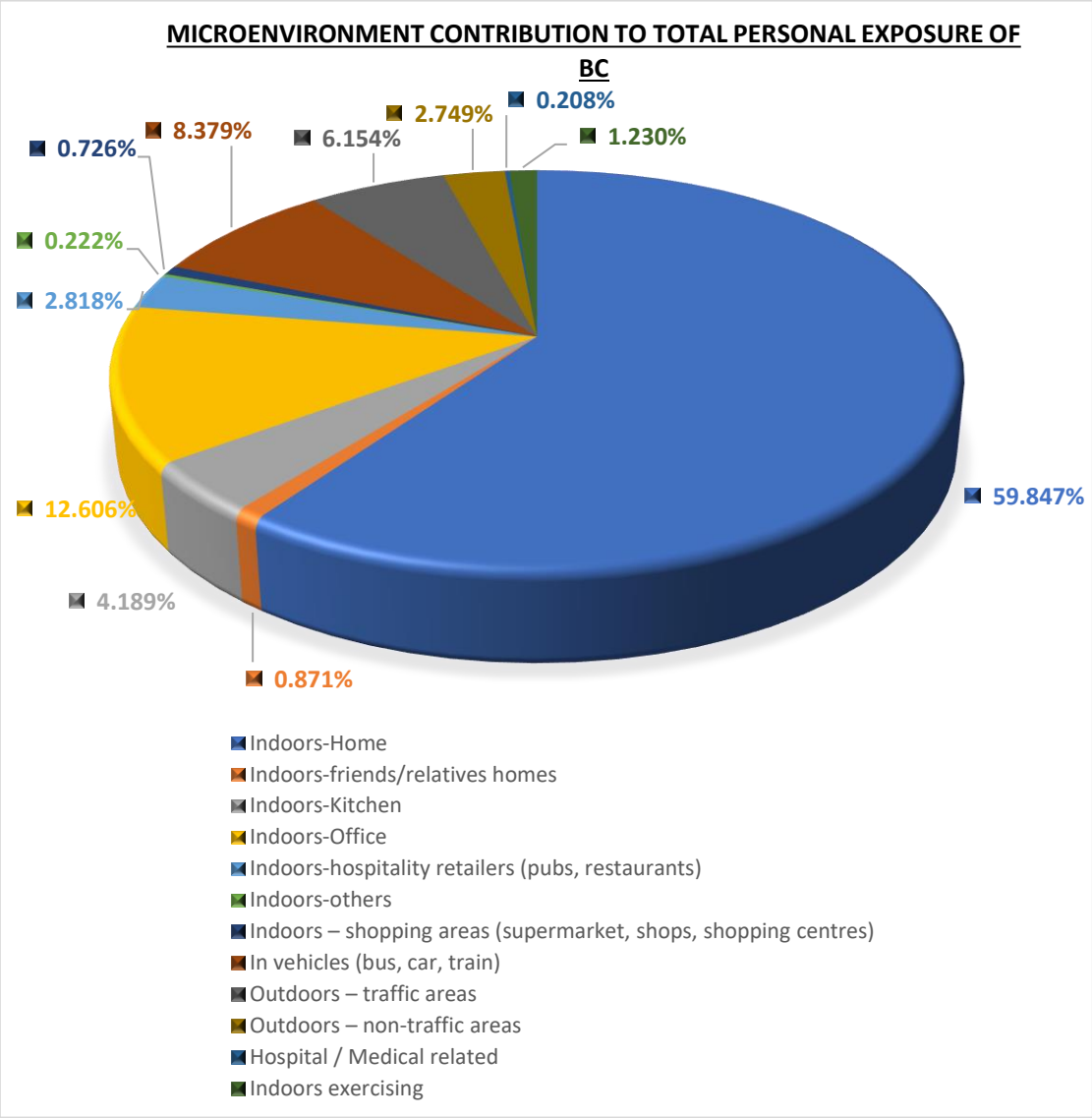

Figure 4: Total microenvironment contribution to BC

4.3.4.2 Contribution to Personal Exposure Associated with Different Activities and Microenvironments – $PM_{2.5}$ Results

4.3.4.2.1 Activities Contribution to Personal Exposure of $PM_{2.5}$

Results from Table 3 in Appendix 5 show that indoor activities at rest (i.e. sleeping, relaxing) contribute the most to personal exposure for 22 subjects; contributions range between 22.6% (ID 25) to 77.7% (ID 32).

4.3.4.2.2 Activities Contribution to All Subjects' Exposure in Total of $PM_{2.5}$

Figure 5 illustrates results shown in Table 3 in Appendix 5 for activities contribution to personal exposure of $PM_{2.5}$ for all the 40 subjects in total, at 5 minutes' intervals for 4 consecutive days, where the total exposure was calculated for the whole sampling period. Results show that indoor activities at rest (i.e. sleeping, relaxing) contribute the most to personal exposure, with a percentage of 26.8%.

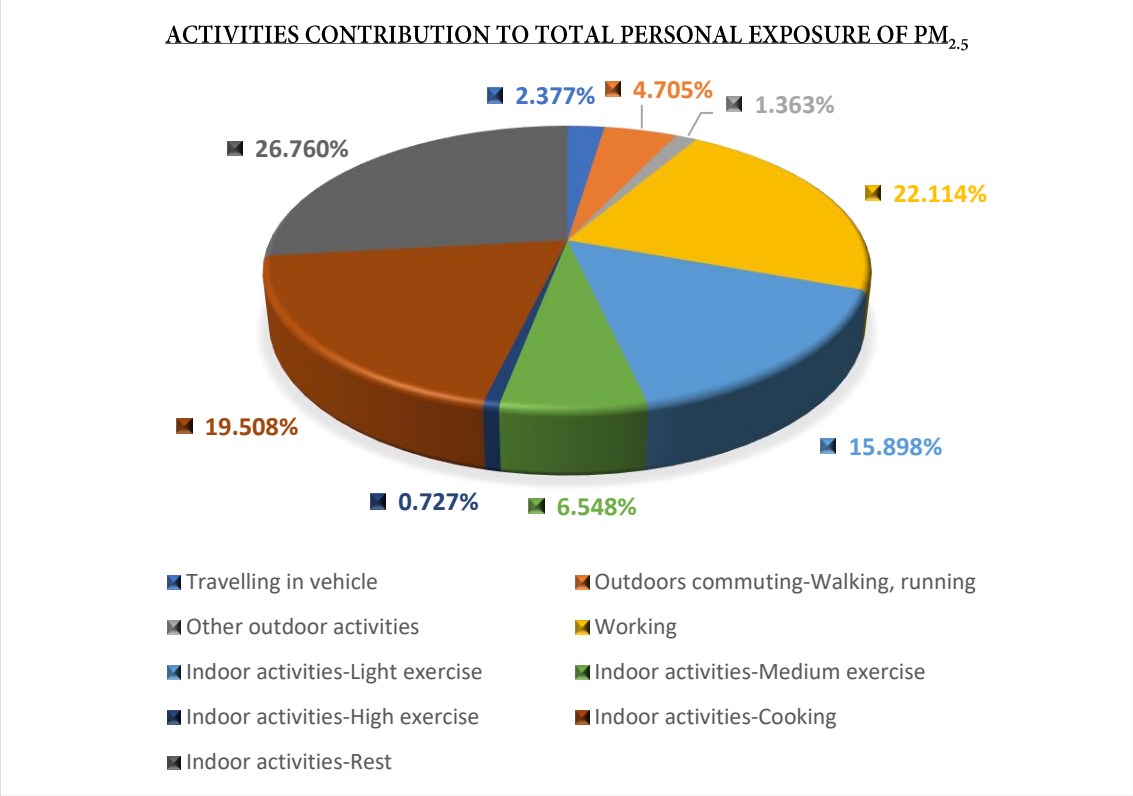

Figure 5: Total activity contribution to $PM_{2.5}$

4.3.4.2.3 Microenvironments Contribution to Personal Exposure of $PM_{2.5}$

Results from Table 4 in Appendix 5 show that indoors at home contributes the most to personal exposure for 38 subjects, with contributions ranging between 39.3% (ID 16) and 97.5% (ID 1).

4.3.4.2.4 Microenvironments Contribution to All Subjects' Exposure in Total of $PM_{2.5}$

Figure 6 illustrates results presented in Table 4 in Appendix 5 for microenvironments contribution to personal exposure of $PM_{2.5}$ for all the 40 subjects in total, at 5 minutes' intervals for 4 consecutive days, where the total exposure was calculated for the

whole sampling period. Results show that indoors at home contributes the most to personal exposure with a percentage of 62.2%.

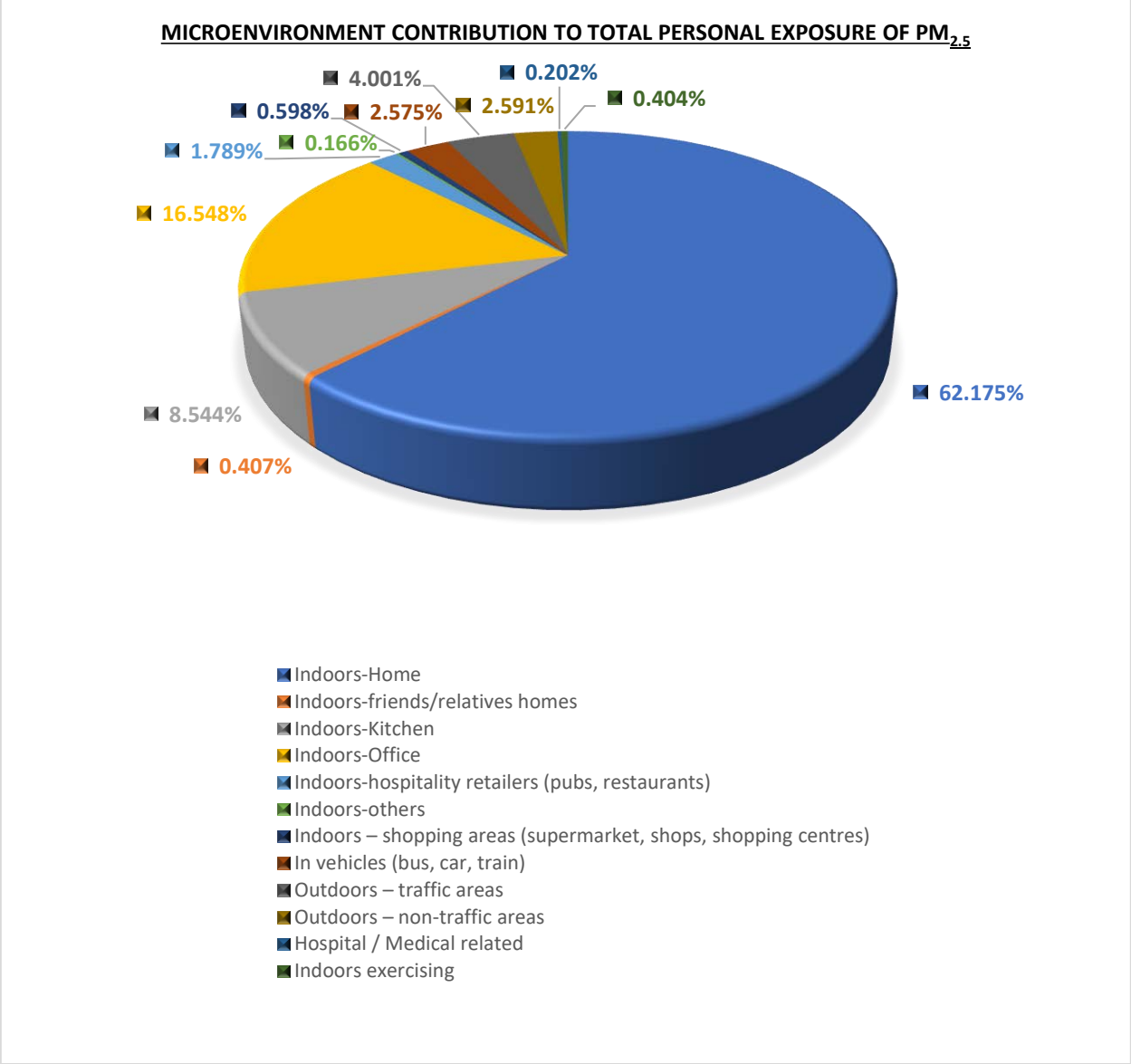

Figure 6: Total microenvironment contribution to $PM_{2.5}$

4.3.4.3 Contribution to Personal Exposure Associated with Different Activities and Microenvironments – UFP Results

Note: There is no UFP data for ID 37 as this was when the sensors were not working and been sent to the manufacturer for repair.

4.3.4.3.1 Activities Contribution to Personal Exposure of UFP

Results from Table 5 in Appendix 5 show that indoor activities at rest (i.e. sleeping, relaxing) contributes the most to personal exposure for 14 subjects, with contributions ranging between 29.7% (ID 25) to 76.3% (ID18), followed by indoor activities with light exercise (e.g. socializing) for 10 subjects, with contributions ranging between 31.705% (ID 29) to 73.5% (ID 8).

4.3.4.3.2 Activities Contribution to All Subjects' Exposure in Total of UFP

Figure 7 illustrates results shown in Table 5 in Appendix 5 for activities contribution to personal exposure of UFP for all the 40 subjects in total, at 5 minutes' intervals for 4 consecutive days, where the total exposure was calculated for the whole sampling period. Results show that indoor activities with light exercise (e.g. socializing) contribute the most to personal exposure, with a percentage of 27.3%.

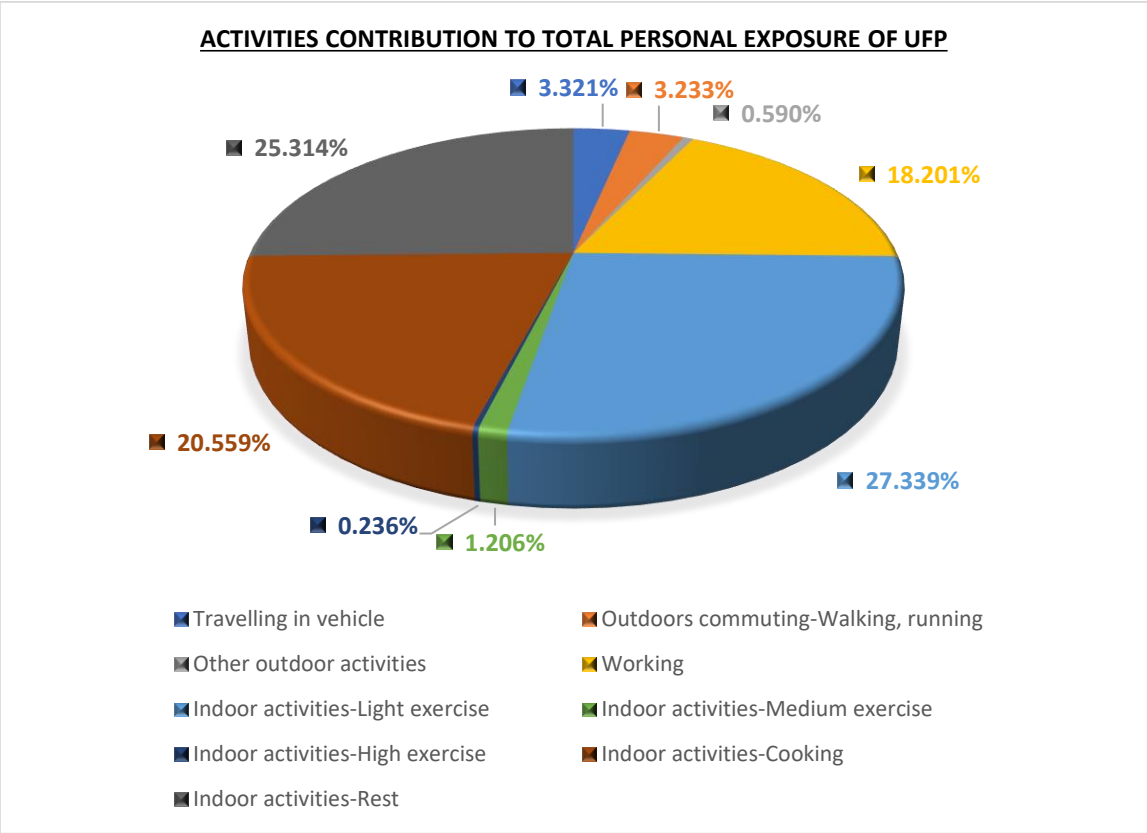

Figure 7: Total activity contribution to UFP

4.3.4.3.3 Microenvironments Contribution to Personal Exposure of UFP

Results from Table 6 in Appendix 5 show that indoors at home contributes the most to personal exposure for 32 subjects, with contributions ranging between 49.5% (ID 5) and 99.5% (ID 32).

4.3.4.3.4 Microenvironments Contribution to All Subjects' Exposure in Total of UFP

Figure 8 illustrates results shown in Table 6 in Appendix 5 for microenvironments contribution to personal exposure of UFP for all the 40 subjects in total, at 5 minutes' intervals for 4 consecutive days, where the total exposure was calculated for the

whole sampling period. Results show that indoors at home contributes the most to personal exposure with a percentage of 66.9%.

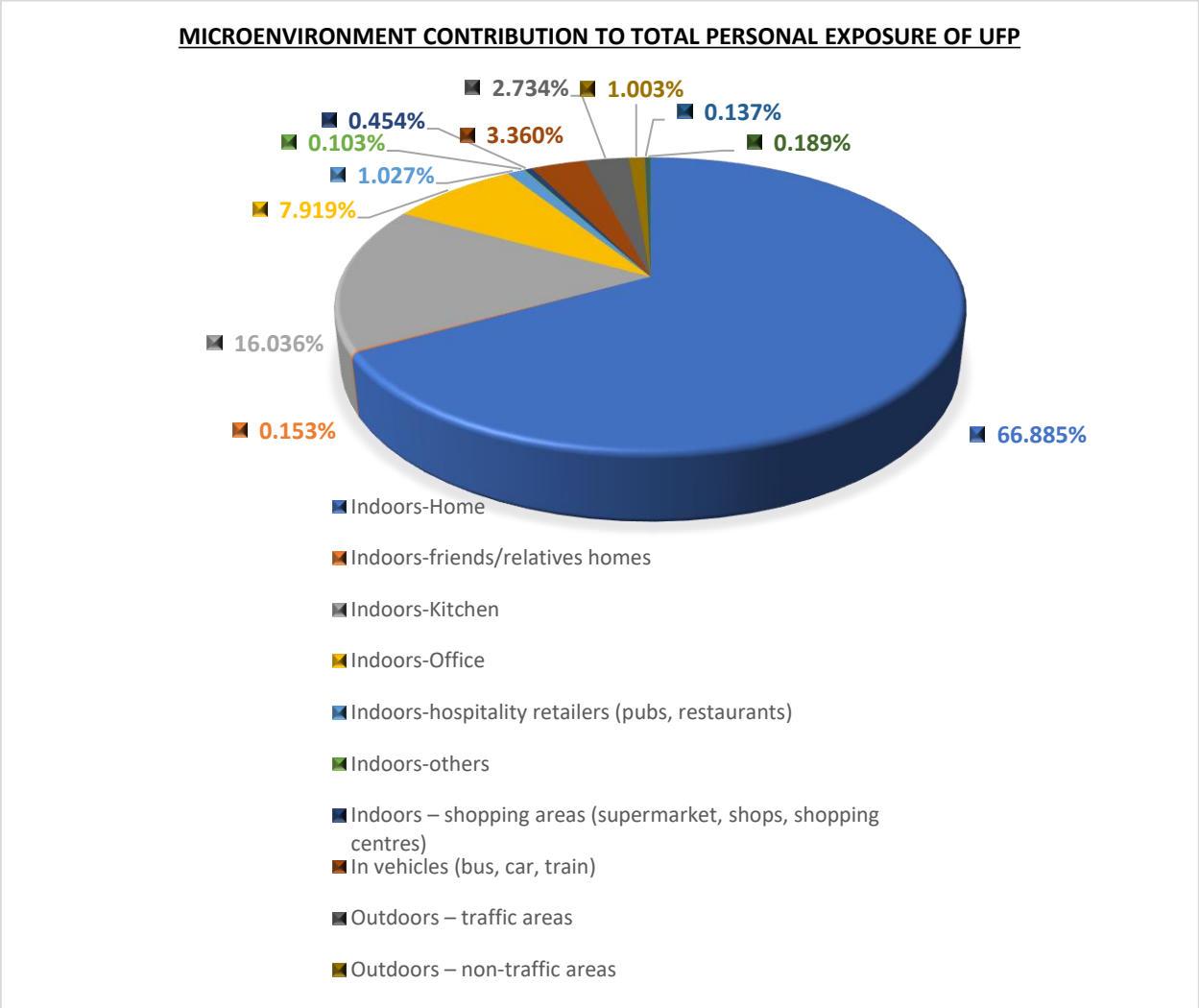

Figure 8: Total microenvironment contribution to UFP

4.3.4.4 Activities and microenvironments contribution to personal exposure of BC, $PM_{2.5}$, and UFP

The results support the hypothesis that activities related to residential indoors contribute the most to personal exposure. As mentioned in the literature, people spend most of their time indoors at home (Delgado-Saborit et al., 2011, Hinwood et al., 2003, Jenkins et al., 1992, Lai et al., 2004, Thatcher and Layton, 1995), where pollutants are produced from different activities such as candle burning and ETS (Apte and Salvi, 2016), and where the airborne particles can remain for many hours (Hussein et al., 2006).

4.4 Discussion

4.4.1 Pollutants Associated the Most with Activities Conducted and Microenvironments Visited by Subjects

The results from activities for the three pollutants show some similarities in terms of the highest concentrations related to activities. Results for BC and $PM_{2.5}$ show the highest three activities are travelling in vehicles, other outdoor activities, and outdoors commuting, while it is travelling in vehicles for UFP. However, the rankings of these activities are different, as for BC travelling in vehicles comes first and outdoors commuting comes third, while the opposite is true for $PM_{2.5}$. Findings for $PM_{2.5}$ support the findings from Gulliver and Briggs (2007) research in which people were exposed to higher PM while walking than while in cars. Other outdoors activity is in second place for both BC and $PM_{2.5}$. For UFP however, travelling in vehicles comes

second, cooking is the highest activity and indoors activity-medium exercise is the third highest activity.

Concentrations associated with other outdoors activities include activities that produce high BC, and $PM_{2.5}$ concentrations such as barbequing. It is well known that BC and $PM_{2.5}$ are emitted from vehicles exhausts, which is linked to the activities travelling in vehicles and outdoors commuting.

Although encouraging people to reduce using cars and walk instead will decrease the pollution (e.g. PM) in the atmosphere, walking may increase the exposure to the pollutants. For example, walking means longer journeys than car journeys, so people are exposed to pollutants for longer time periods (Gulliver and Briggs, 2004); further, since cars are a closed microenvironment, and isolated from outdoor pollution, it can reduce the personal exposure to outside atmospheric pollutants (Gulliver and Briggs, 2007).

Cooking normally produces particles due to burning for heating and vapor produced from food cooking. For indoors activities - medium exercise like household chores, which include using cleaning products and incenses, air fresheners, perfumes, etc., can contribute in increasing the particles indoors (Apte and Salvi, 2016).

The activity showing the lowest concentrations for both BC and $PM_{2.5}$ is working, along with indoors activities – rest for BC. For UFP the lowest concentration is associated with indoors activities – high exercise.

On the other hand, results from microenvironments highlight differences in highest and lowest levels of concentration all three pollutants. For BC, the highest concentration is associated with in vehicles, where BC can get in the vehicles through

windows and other openings. As for $PM_{2.5}$, the highest concentration is associated with indoors – others, which includes churches, where subjects may have been exposed to candle burning.

It is also noticeable that the third highest concentration associated with microenvironment for BC is outdoors traffic areas, while for $PM_{2.5}$ it is the outdoors non-traffic areas. This could be related to other factors affecting the concentration, such as emission factors as explained in the literature review chapter, also other factors such as exposure to tobacco smoke, or that the traffic-areas and non-traffic areas are close to each other, or the roads for non-traffic areas are narrow, and the pollutants are trapped and accumulate in the atmosphere.

Interestingly, UFP concentrations are highly associated with hospital/ medical locations, because these microenvironments are supposed to be sanitized and free from any pollutant sources, but these high concentrations may be due to UFP outdoors concentrations, which can get into the medical indoors locations (Morawska et al., 1998). This can also be applicable to indoors shopping areas, where we see the second highest BC concentrations.

However, the microenvironments with lowest pollutant concentrations are indoors – others for BC, indoors office for $PM_{2.5}$, and indoors exercising for UFP.

4.4.2 Overview of Pollutant Contribution to Personal Exposure Associated with Different Activities and Microenvironments

Results from the three pollutants shows that indoors activities (i.e. rest, relaxing), indoors activities doing light exercise, and indoors at home microenvironment contribute the most to personal exposure, which is where people spent the majority of their time (Delgado-Saborit et al., 2011, Hinwood et al., 2003, Jenkins et al., 1992, Lai et al., 2004, Thatcher and Layton, 1995). This highlights the fact that pollutant concentration or dose, and duration of exposure time are essential factors to assess the effect of the pollutant (Bunce and Remillard, 2003). Indoors at home, then, provides a good microenvironment to use as surrogate to assess personal exposure, instead of central sites.

Studies showed that long term exposure to low concentrations of pollutants have an adverse effect on human health (Connell et al., 2016; Olmo et al., 2011; Raaschou-Nielsen et al., 2013). Several indoors activities produce the pollutants BC, $PM_{2.5}$, and UFP, such as cooking, candle or essence burning (Apte and Salvi, 2016). Also, as mentioned previously, UFP can get into indoors environments through windows and doors and increase pollutant concentrations (Hussein et al., 2005; Morawska et al., 1998). These low levels can remain indoors for a long time, so people are constantly inhaling the pollutants whether they are awake or asleep (Hussein et al., 2006). Some results show that people spent very little time sleeping. It was thought this could be because another member of the household unplugged the sensor or tripped over the wires, thus disconnecting the sensor from the mains and leading the sensor to turn off after running out of charge. In the case of the DiSCmini sensor, the corona voltage gets very high and stops measuring, and the corona wire needs to be cleaned. To reduce this problem, a note was attached with the sensors reminding to

ensure the chargers were not disconnected from the mains, in addition to the oral instructions already given to the subject.

4.5 Conclusion

The activities found to be linked to the highest concentrations of BC and $PM_{2.5}$ are travelling in vehicles, other outdoors activities, and outdoors commuting. UFP shows the same results as BC and $PM_{2.5}$ in terms of travelling in vehicles activity, but the highest concentration found is linked to cooking.

Findings also provide strong evidence from the three pollutants that indoors activities (i.e. rest, relaxing), is the highest contributor to personal exposure, in addition to indoor activities with light exercise (e.g. socializing) which was found in the UFP results.

The microenvironments found to be linked to the highest concentrations of pollutants are in vehicles for BC, indoors-others for $PM_{2.5}$, and finally for hospital/ medical related for UFP. This was unexpected, given that these places are supposed to be clean and free from any pollution sources, but this could be because of the outdoors UFP concentrations, which can get in the medical indoors through openings such as doors and windows.

These findings from the three pollutants results also provide strong evidence that indoors at home microenvironments are the highest contributors to personal exposure, because this is where people spent the majority of their times.

Although some activities and microenvironments have low concentrations of pollutants, long term exposure to them can cause adverse health effects. We can also

link the results to the findings in Chapter 3, where the research shows that central sites cannot be used as a surrogate to assess personal exposure. Since the finding in this chapter shows indoors at home is the major contributor to personal exposure, where people spend most of their time, home monitors indoors houses are useful as a surrogate to assess human exposure. In the future, companies may be able to develop built-in monitors inside houses, to calculate different pollutants concentrations.

Certain measures can be recommended to lower the personal exposure to air pollutants:

- Use air purifiers and filters
- Turn on the extractor fans during and after cooking
- Reduce the use of household cleaners, candles and incenses
- Encourage the household smokers to smoke outdoors, and close the windows and doors while they are smoking outside
- Use routes with less traffic intensity if possible, and keep away from busy roads
- Regular vacuuming
- Take walks to breathe fresh air in low polluted areas such as gardens
- Buy a vehicle with low pollutants emissions (e.g. electric cars)
- Carry out regular checks on vehicle’s exhaust to make sure it meets the emission standards

CHAPTER 5 CONTRIBUTION OF INDOOR AND OUTDOOR SOURCES ON PERSONAL EXPOSURES: EFFECT OF COOKING WITH GAS-APPLIANCES AND LIVING NEAR ROADSIDES

This project is part of a cohort study (Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures) funded by the Health Effects Institute (HEI), which is a non-profit corporation chartered in 1980 as an independent research organization to provide high-quality, impartial, and relevant science on the health effects of air pollution. This research will appear in the report "Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures", in which the researcher is a co-author, but in this thesis the researcher wrote all the content herself. Recruitment of subjects, sampling, preparation of equipment and sensors, data collection, data insertion, and data analysis were all done by the researcher of this thesis, unless stated otherwise in the text.

5.1 Introduction and Overview

Results from Chapter 4 indicated that pollutant concentrations were high during indoor activities such as cooking (in particular the UFP results), also the indoors at home microenvironment provided the highest contribution to personal exposure of pollutants. There are indoor and outdoor factors that may affect personal exposure during cooking, such as type of stove (i.e. gas, electricity), and during time spent at home such as house location (i.e. busy roads or quiet roads).

As mentioned in the literature review, pollutants from traffic related activities and microenvironments can affect human health, and these pollutants can get indoors through windows and doors. People who live on busy roads are more likely to suffer adverse health effects (Gulliver and Briggs, 2007). A study by Carey et al. (2016) in London suggested that people living on or close to busy roads may increase the risk of exacerbating health problems related to heart failure and pneumonia at short-term exposure. Also,Jarvis et al., (1996) mentioned that people who use gas stoves at home experience more respiratory-related health problems.

A study by He et al. (2004) found that indoors UFP concentrations can be elevated by up to 5 times due to activities related to cooking, including frying, grilling, stove use, toasting, in addition to other activities including fan heaters and candles (e.g. vaporizing eucalyptus oil), and that $PM_{2.5}$ concentrations can be higher than background levels by up to 3, 30, and 90 times due to smoking, frying and grilling respectively. Géhin et al. (2008) found highest emissions concentrations when cooking meat or fish whether in stove or in oven. Other cooking related activities also affect the $PM_{2.5}$ concentrations at home, including baking, broiling, basting and roasting, which can affect human health and can lead to morbidity and mortality (Apte and Salvi, 2016).

Since people spend the majority of their time in the indoor home environment, normally they will be exposed to particles including the three pollutants involved in this research, which can be produced from different sources, such as cooking related activities, pet dander, ETS, burning of candles and incense sticks, household cleaning agents (Apte and Salvi, 2016), and from outdoors (Hussein et al., 2005).

These concentrations can remain indoors even after conducting these activities, and people inhale the particles even during sleeping times, especially from cooking (which is a major indoor source), tobacco smoke, and airborne from incense stick burning, where the airborne particles from tobacco smoke and incense stick burning remain for longer than particles from cooking (Hussein et al., 2006).

Even though the subjects are non-smokers, some of their guests or roommates smoked occasionally. Hussein et al.'s (2006) study found that fine particles emitted from smoking one cigarette are equal to the amount of particles produced during approximately half an hour of cooking, and that airborne particles from tobacco may remain up to ten hours.

This chapter assesses the effect of cooking with gas and electrical appliances on personal exposure, and the effect of living near a busy road on personal exposure during indoor activity (i.e. sleeping), and during time spent in an indoors microenvironment (i.e. home).

5.2 Objectives

- To determine personal exposure during time spent at home, an analysis was conducted between houses using a gas stove compared to houses using an electric stove; and then between houses located near busy roads compared to houses located away from busy roads.
- To determine personal exposure during time spent in cooking, an analysis was conducted during cooking times using gas stoves compared to cooking using electric stoves, in houses located both near and away from busy roads.

- To determine personal exposure during time spent in sleeping, an analysis was conducted at houses located near busy roads compared to houses located away from busy roads in both houses using gas stoves and houses using electric stoves.

5.3 Methodology

The same data for the 40 subjects recruited in Chapter 3 were used in this chapter, each 10 subjects were grouped in a category according to their home location to traffic (traffic side/ non-traffic side), and type of stove hob (Gas/Electricity). Table 7 show the groups and their key determinants

Table 7: Subjects groups by key determinant

Group	Traffic exposure	Cooking gas stove	Number of subjects	Total
1	Yes	Yes	10	40
2	Yes	No	10	
3	No	Yes	10	
4	No	No	10	

5.3.1 Data Analysis

Minitab statistical software version 17.1.0 was used to extract the results of the following:

A. Personal exposure in houses using gas stoves compared to houses using electric stoves: Busy roads

-Personal exposure during cooking times, and during time spent in houses, using gas stoves compared to cooking using electricity.

B. Personal exposure in houses using gas stoves compared to houses using electric stoves: Quiet roads

- Personal exposure during cooking times, and during time spent in houses, using gas stoves compared to cooking using electricity.

C. Personal exposure in houses located near busy roads compared to houses located in quiet roads: Gas stove

- Personal exposure during sleeping times, and during time spent at home, in houses located near busy roads compared to houses located near quiet roads.

D. Personal exposure in houses located in busy roads compared to houses located away from traffic roads: Electric stove

- Personal exposure during sleeping times, and during time spent at home, in houses located near busy roads compared to houses located near quiet roads.

5.4 Results

For each of BC, $PM_{2.5}$ and UFP the analysis starts with the normality results, followed by the t-test and Mann-Whitney test results. Results from all outputs are shown in Appendix 6. All test types used in this chapter were explained in Chapter 3.

The tested hypotheses are:

1- personal exposure while cooking with a gas stove is higher than cooking with an electrical stove.

2- personal exposure to pollutants while spending time in houses located near busy roads, or using gas stoves are higher than time at houses located near quiet roads.

3- personal exposure while sleeping in houses located in busy roads is higher than in houses located near quiet roads.

The tested hypotheses are first, that the data are not normally distributed; second, means and medians are not equal. If in the t-test the null means data is normally distributed, then the alternative is that data is not normally distributed, for the Mann-Whitney test the null is the two means/medians are equal, the alternative is they are not equal:

A- Normality hypothesis:

H0: the data in the sites is normally distributed.

H1: the data in the sites is not normally distributed.

B- Difference between two cases hypothesis:

For t-test or Mann-Whitney tests:

H0: Means/ medians are equal.

H1: Means/ medians are not equal

5.4.1 Statistical and Descriptive Results

The following charts Figure 9 to Figure 14 illustrate the mean and standard deviation for each pollutant, from the key determinants and activities, and Table 6 summarizes the results for each pollutant, from the key determinants and activities. Statistical outputs are shown in Appendix 6.

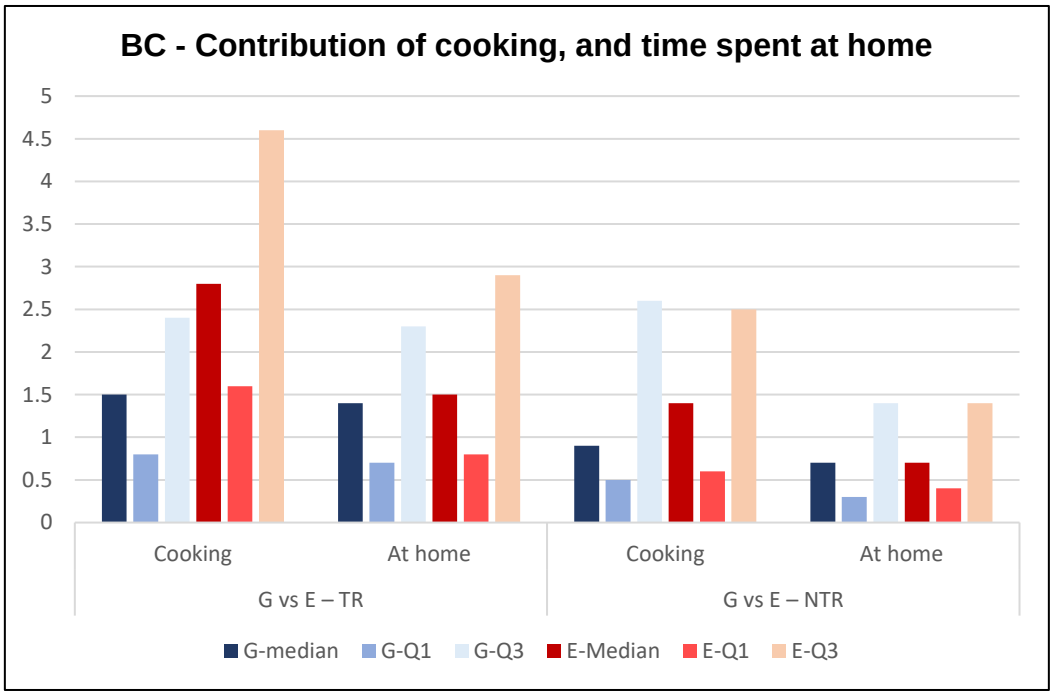

Figure 9: BC median, and first and third quartiles (Q1, Q3) for contribution of cooking, and time spent at home, in houses located either near or away from busy roads, using either gas or electric stove, on personal exposure, at 5 minutes time interval. The pollutant measurement distributions are non-normal (see main text) and the median is a better indicator of the average distribution

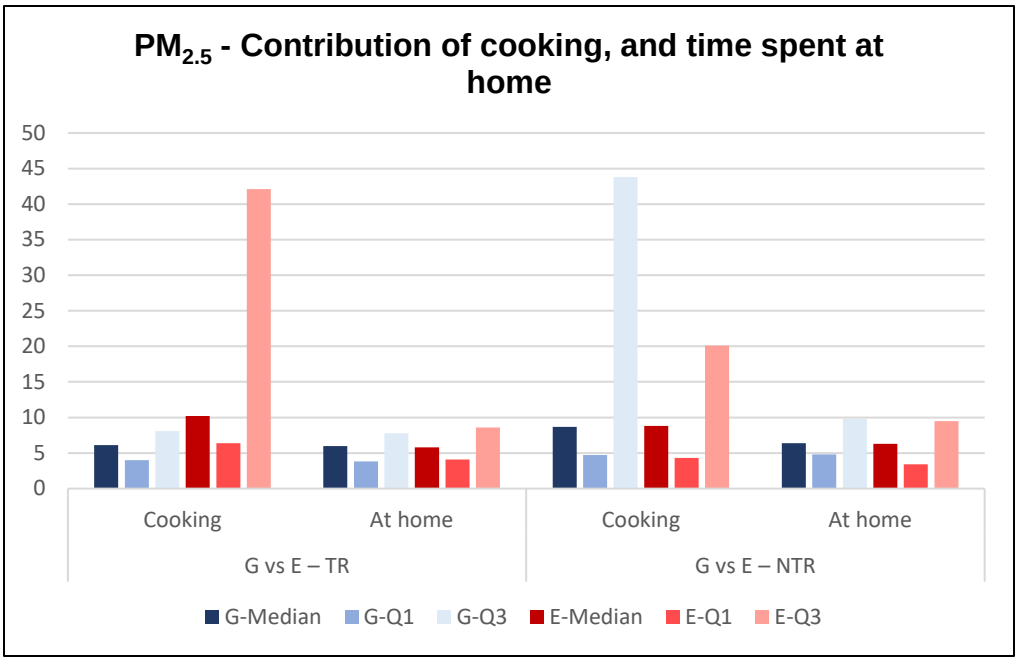

Figure 10: $PM_{2.5}$ median, and first and third quartiles (Q1, Q3) for contribution of cooking, and time spent at home, in houses located either near or away from busy roads, using either gas or electric stove, on personal exposure, at 5 minutes time interval. The pollutant measurement distributions are non-normal (see main text) and the median is a better indicator of the average distribution

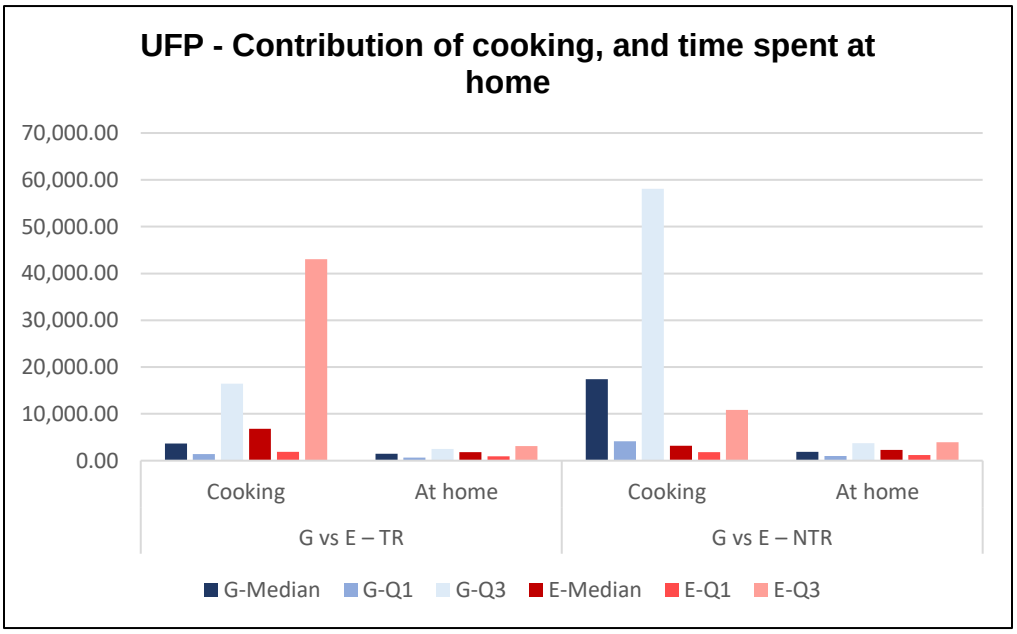

Figure 11: UFP median, and first and third quartiles (Q1, Q3) for contribution of cooking, and time spent at home, in houses located either near or away from busy roads, using either gas or electric stove, on personal exposure, at 5 minutes time interval. The pollutant measurement distributions are non-normal (see main text) and the median is a better indicator of the average distribution

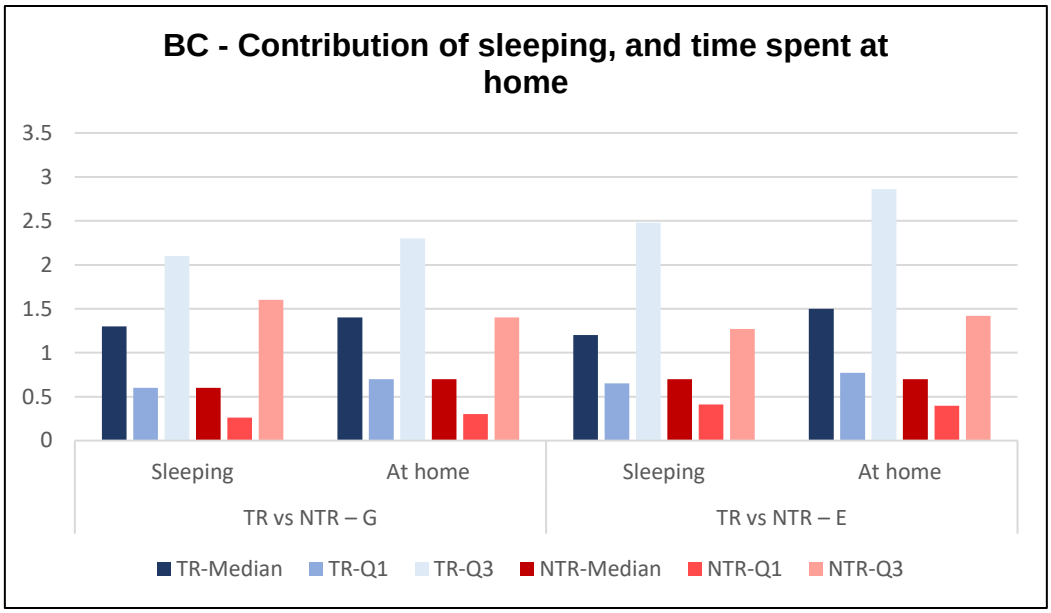

Figure 12: BC median, and first and third quartiles (Q1, Q3) for contribution of sleeping, and time spent at home, in houses located either near or away from busy roads, using either gas or electric stove, on personal exposure, at 5 minutes time interval. The pollutant measurement distributions are non-normal (see main text) and the median is a better indicator of the average distribution

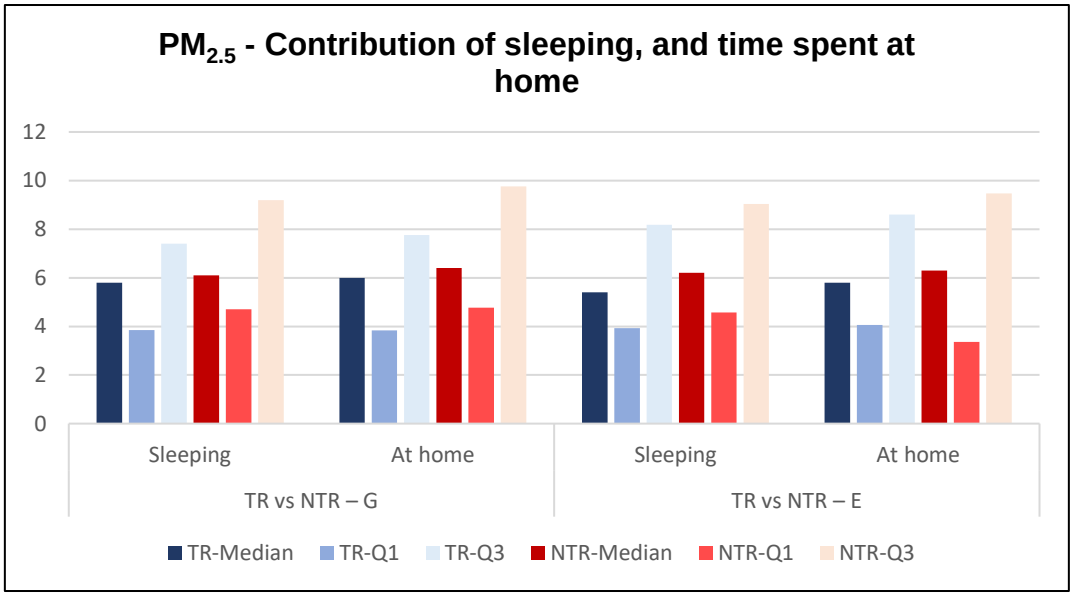

Figure 13: $PM_{2.5}$ median, and first and third quartiles (Q1, Q3) for contribution of sleeping, and time spent at home, in houses located either near or away from busy roads, using either gas or electric stove, on personal exposure, at 5 minutes time interval. The pollutant measurement distributions are non-normal (see main text) and the median is a better indicator of the average distribution

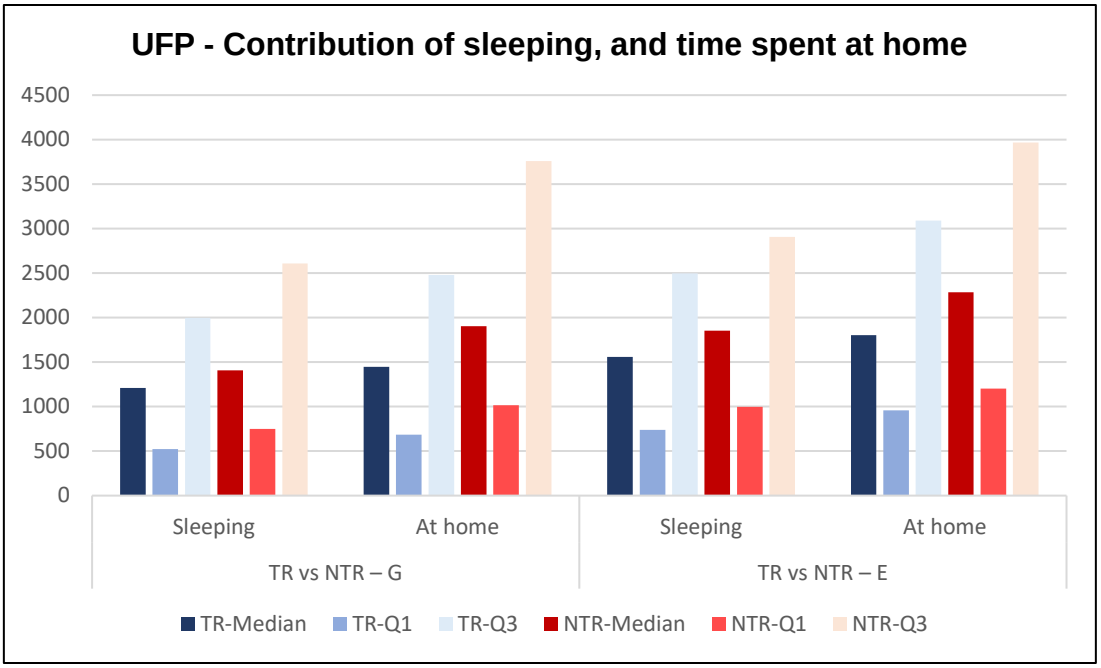

Figure 14: UFP median, and first and third quartiles (Q1, Q3) for contribution of sleeping, and time spent at home, in houses located either near or away from busy roads, using either gas or electric stove, on personal exposure, at 5 minutes time interval. The pollutant measurement distributions are non-normal (see main text) and the median is a better indicator of the average distribution

Table 8: Contribution of cooking, time spent at home, and sleeping in houses located either near or away from busy roads, using either gas or electric stove, on personal exposure, at 5 minutes time interval

Group	Activity	Pollutant	Key determinant	Median	M-W* test *p-valuel*	N*
G* vs E* – TR*	Cooking	BC*	G	1.5	0.000	464
			E	2.8		341
		$PM_{2.5}$*	G	6.1	0.000	435
			E	10.2		325
		UFP*	G	3,674.1	0.0005	256
			E	6,829.8		195
	Time spent at home	BC	G	1.4	0.000	8376
			E	1.5		7942
		$PM_{2.5}$	G	6.0	0.0571	7805
			E	5.8		7526
		UFP	G	1,445.3	0.0000	4675
			E	1,801.7		3545
G vs E – NTR*	Cooking	BC	G	0.9	0.0028	377
			E	1.4		658
		$PM_{2.5}$	G	8.7	0.0019	367
			E	8.8		594
		UFP	G	17,439	0.0000	232
			E	3,184		370

	Time spent at home	BC	G	0.7	0.0327	6886
			E	0.7		8142
		$PM_{2.5}$	G	6.4	0.0000	6389
			E	6.3		7052
		UFP	G	1,904.9	0.0000	4431
			E	2,283.2		4596
TR vs NTR – G	Sleeping	BC	TR	1.3	0.000	5174
			NTR	0.6		4374
		$PM_{2.5}$	TR	5.8	0.0000	4874
			NTR	6.1		4097
		UFP	TR	1209.5	0.0000	2790
			NTR	1407.6		2672
	Time spent at home	BC	TR	1.4	0.000	8376
			NTR	0.7		6886
		$PM_{2.5}$	TR	6.0	0.0000	7805
			NTR	6.4		6389
		UFP	TR	1,445.3	0.0000	4675
			NTR	1,904.9		4431
TR vs NTR – E	Sleeping	BC	TR	1.2	0.000	5236
			NTR	0.7		5011
		$PM_{2.5}$	TR	5.4	0.0000	5026
			NTR	6.2		4315
		UFP	TR	1,558.6	0.0000	2448
			NTR	1,854.4		2357
	Time spent at home	BC	TR	1.5	0.000	7942
			NTR	0.7		8142
		$PM_{2.5}$	TR	5.8	0.0000	7526
			NTR	6.3		7052
		UFP	TR	1,801.7	0.0000	3545
			NTR	2283.2		4596

*G: using gas stove

*E: using electric stove

*TR: houses located near busy roads

*NTR: houses located near quiet roads

*M-W: Mann-Whitney test

*N: number of measurements

- Normality results: Statistical analysis for normality for all the results from BC, $PM_{2.5}$, and UFP are not normally distributed.

- Contribution of indoor and outdoor sources on personal exposures results:

A. Personal exposure in houses using gas stoves compared to houses using electric stoves: Busy roads

A.1. Personal exposure during cooking times using gas stove compared to cooking using electricity: Busy roads

The tests results for BC, $PM_{2.5}$ and UFP indicate the median for electricity was higher than gas, (M-W test p-value=0.000), (M-W test p-value=0.000), (M-W test p-value=0.0005) respectively.

A.2. Personal exposure during time spent at home using gas stove compared to houses using electric stove: Busy roads

BC and UFP results indicate the median for electricity was higher than gas (M-W test p-value=0.000), (M-W test p-value=0.0000) respectively. However, for $PM_{2.5}$ the median is the same for gas and electricity (M-W test p-value=0.0571).

B. Personal exposure in houses using gas stoves compared to houses using electric stoves: Quiet roads

B.1. Personal exposure during cooking times using gas stove compared to cooking using electricity: Quiet roads

BC results show that the median for electricity was higher than for gas (M-W test p-value=0.0028). As for the $PM_{2.5}$ median is very slightly higher for electricity than gas (M-W test p-value=0.0019). UFP results indicate that the median for gas is higher than electricity (M-W test p-value=0.0000).

B.2. Personal exposure during time spent in houses using gas stove compared to houses using electric stove: Quiet roads

Both BC and UFP medians are higher for electricity than gas (M-W test p-value=0.0327), (M-W test p-value=0.0000) respectively. $PM_{2.5}$ results indicate that the median is very slightly higher for gas than electricity (M-W test p-value=0.0000).

C. Personal exposure in houses located near busy roads compared to houses located near quiet roads: Gas stove

C.1. Personal exposure during sleeping times in houses located near busy roads compared to houses located near quiet roads: Gas stove

BC results indicate the median for houses near busy roads was higher than those near quiet roads (M-W test p-value=0.000). In contrast, the $PM_{2.5}$ and UFP medians are higher for houses near quiet roads than for those near busy roads (M-W test p-value=0.0000), (M-W test p-value=0.0000) respectively.

C.2. Personal exposure during time spent at houses located near busy roads compared to houses located near quiet roads: Gas stove

Results for BC indicate that the median for busy roads was higher than quiet roads (M-W test p-value=0.000). In contrast, the medians for $PM_{2.5}$ and UFP are higher for quiet roads than busy roads (M-W test p-value=0.0000), (M-W test p-value=0.0000) respectively.

D. Personal exposure in houses located near busy roads compared to houses located near quiet roads: Electric stove

D.1. Personal exposure during sleeping times in houses located in busy roads compared to houses located away from busy roads: Electric stove

The tests results for BC indicate that the median for busy roads was higher than for quiet roads (M-W test p-value=0.000). The median is higher for quiet roads than for busy roads for both $PM_{2.5}$ and UFP (M-W test p-value=0.0000), (M-W test p-value=0.0000) respectively.

D.2. Personal exposure during time spent at houses located in busy roads compared to houses located near quiet roads: Electric stove

The test results for BC indicate median for busy roads was higher than for quiet roads (M-W test p-value=0.000). In contrast, the medians for $PM_{2.5}$ and UFP are higher for quiet roads than busy roads, (M-W test p-value=0.0000), (M-W test p-value=0.0000) respectively.

5.5 Discussion

The aim of this chapter is to assess the effect of cooking with gas-appliances as opposed to electric appliances, and living near busy roads during sleeping, cooking, and time spent at home.

Statistical results show that all data for the three pollutants are not normally distributed. Table 8 summarizes the results for the contribution of cooking, time spent at home, and sleeping in houses located either near or away from busy road, using either gas or electric stove, on personal exposure for each of the three pollutants,

including arithmetic mean, standard deviation, median, t-test *p*-value, and Mann-Whitney p-value. The findings are as follows:

Personal exposure during cooking

Personal exposure to BC during cooking, in both houses located near busy roads, and away from busy roads, was slightly higher for using electric stove than using gas stove (mean, standard deviation, G-TR: 3.1 µg/m³, 8.3), (E-TR: 4.9 µg/m³, 7.7), (G-NTR: 1.8 µg/m³, 2.3), (E-NTR: 2.3 µg/m³, 3.2).

In houses located near busy roads, personal exposure to $PM_{2.5}$ during cooking is the same for using electric and using gas stoves (p-value: 0.587), but the median is higher for using electric stove than using gas stove (P-value: 0.000). However, in houses located away from busy roads, the mean is higher for using gas stove (50.0 µg/m³, 130) than using electric stove (24.7 µg/m³, 64.4).

Personal exposure to UFP during cooking in houses located near busy roads is the same for using gas or electric stoves (p-value: 0.101), but the median is higher for using electric stove than using gas stove (p-value: 0.0005). However, in houses located away from busy roads, personal exposure during cooking using gas stove (40,711 #/cc, 54,776), is higher than using electric stove (14,812 #/cc, 29,121).

Personal exposure during time spent at home

Personal exposure to BC during time spent at houses located near busy roads using electric stove (2.9 µg/m³, 14.9) was higher than using gas stove (1.9 µg/m³, 2.5). However, in houses located away from busy roads, the mean for using electric and gas stoves are the same (p-value: 0.472), but the median is higher for using electric stove than using gas stove (p-value: 0.0327). Personal exposure during time spent at

houses located near busy roads was higher than the ones located away from busy roads for both using gas or electric stoves (TR-G:1.9 µg/m³, 2.5), (NTR-G: 1.4 µg/m³, 3.4), (TR-E: 2.7 µg/m³, 14.9), (NTR-E: 1.4 µg/m³, 2.2).

Personal exposure to $PM_{2.5}$ during time spent at houses located near busy roads using gas stove (10.6 µg/m³, 53.6), is higher than using electric stove (8.5 µg/m³, 14.5). However, in houses located away from busy roads, using electric stove (16.0 µg/m³, 101), is higher than using gas stove (13.0 µg/m³, 23.3), but the median is slightly higher for using gas stove than using electric stove (p-value: 0.000). Personal exposure during time spent at houses located away from busy roads is higher than houses located in busy roads in both houses using gas or electric stoves (TR-G: 10.6 µg/m³, 53.6), (NTR-G: 13.0 µg/m³, 23.3), (TR-E: 8.5 µg/m³, 14.5), (NTR-E: 16.0 µg/m³, 101).

Personal exposure to UFP during time spent at houses located near busy roads is the same when using gas or electric stoves (p-value: 0.241), but the median is higher for using electric stove than using gas stove (p-value: 0.0000). This is the same for houses located away from busy roads, where personal exposure using gas or electric stove is the same (p-value: 0.379), but median is higher for using electric stove (p-value: 0.0000). Personal exposure during time spent in houses located away from busy roads is higher than houses located in busy roads, in both houses using gas or electric stoves (TR-G: 4,301 #/cc, 14,608), (NTR-G: 5,406 #/cc, 13,758), (TR-E: 4,634 #/cc, 11,120), (NTR-E: 5,680 #/cc, 15,814).

Personal exposure during sleeping

Personal exposure to BC during sleeping in houses located near busy roads is higher than the ones located away from busy roads, in houses using gas or electric stoves (TR-G: 1.7 µg/m³, 1.8), (NTR-G: 1.4 µg/m³, 3.5), (TR-E: 2.5 µg/m³, 4.3), (NTR-E: 1.3 µg/m³, 2.0).

Personal exposure to $PM_{2.5}$ during sleeping in houses located away from busy roads is higher than houses located near busy roads, in houses using gas or electric stoves (TR-G: 7.0 µg/m³, 12.0), (NTR-G: 12.2 µg/m³, 15.5), (TR-E: 7.5 µg/m³, 11.9), (NTR-E: 9.8 µg/m³, 30.9).

Personal exposure to UFP during sleeping in houses located near and away from busy roads is the same, both in houses using gas (p-value: 0.075), or electric stove (p-value: 0.470), but the median is higher for houses located near quiet roads, both in houses using gas or electric stoves.

Findings from time spent at home are inconsistent with the hypothesis. First, in terms of using electric or gas stove, the results show that BC concentrations during time spent at home using electric stove are higher, while $PM_{2.5}$ concentrations are higher, both for using gas in houses located near busy roads, and for using electricity in houses located near quiet roads. UFP concentrations, using gas or electric stove are the same, although the median from using electricity is higher in both locations. Second, in terms of the house location, only BC results are coherent with the hypothesis, where its concentrations are found to be higher during time spent in houses located near busy roads both using gas or electric stoves. But for both $PM_{2.5}$ and UFP, all results show that concentrations are higher when spending time at home in houses located near quiet roads using gas or electric stoves.

The findings from sleeping only support the hypothesis in BC concentration results, where they are higher for sleeping in houses located in busy roads, using gas or electric stove. By contrast, $PM_{2.5}$ concentrations are found to be higher during sleeping in houses located away from busy roads, using gas or electric stove, while UFP concentrations showed the same results for both locations, although the median from houses located away from busy roads is higher, using gas or electric stove. The results show that using a gas stove at home is not necessarily linked to respiratory problems as Jarvis et al., (1996) claimed, but the findings do confirm that respiratory problems can also be linked to emissions produced by using an electric stove. The result could be affected by other factors such as using candles, cooking method, products cooked, use of household cleaning agents, ETS etc. which can remain indoors for a longer time whether during the day or until midnight during sleeping, in addition to pollutants that can get inside houses from outdoors.

5.6 Conclusion

It is noticeable that contributions from cooking using electric stoves in houses located near busy roads are higher than houses located near quiet roads. We may conclude that living in houses located near busy roads affects the indoors background concentrations of the three pollutants. Hence, it is recommended to reduce the pollution that gets inside (e.g. through windows, doors) from outdoors, by for example using air purifiers, avoiding opening windows during rush hours, and using window and door screens, or to reduce the indoor pollutants concentrations by vacuuming and wiping the dust from surfaces, and using extractor fans during cooking.

We can also conclude that people are exposed to higher BC concentrations during time spent at houses located near busy roads. But they are exposed to higher $PM_{2.5}$ and UFP in houses located near quiet roads. And during sleeping times, people are exposed to higher BC in houses located on busy roads. While they are exposed to higher $PM_{2.5}$ in houses located away from busy roads, this may be also the case for UFP since only the median was shown to be higher.

Further study is needed to investigate the effect of living close to busy roads, taking into account the confounding factors that affect the indoor pollutants concentrations, Ways of controlling this need considering, such as various measures to eliminate or reduce the amount of pollutants, including stopping or reducing the following: candle and incense use, ETS, household cleaning products, aerosols (e.g. hairsprays, air fresheners).

It would also be useful to measure the pollutants concentrations, not only at the personal exposure level and inside houses, but also outside the houses close to the pathways (e.g. windows, doors), and at different distances from the road to these pathways, to assess and compare the amount of pollutants from the traffic side to the amount that enters the house from the traffic.

CHAPTER 6: EFFECTS OF SHORT-TERM EXPOSURE TO PARTICULATE MATTER ON COGNITIVE PERFORMANCE

Some parts of this chapter are taken from Shehab. et al. (n.d.) review "Correlation between short and long-term exposure to air pollution and cognitive performance in adults and elderly: A systematic review", *and from Shehab and Pope paper "Effects of short-term exposure to particulate matter on cognitive performance"*

6.1 Introduction and Overview

Air pollution may have adverse effects on mature nervous system in adults (Liu and Lewis, 2014). Further, (Suglia et al., 2008) mentioned in their study that air pollutants such as ultrafine particles (UFP) from traffic exhausts can be trans-located from the lungs to other organs including the central nervous system, but the association between the effect of air pollution and cognitive functions remains largely unexplored (Chen and Schwartz, 2009, Suglia et al., 2008, Peters et al., 2006).

Commuting including walking, cycling, driving, motorized transportation (i.e. train, bus, car, etc) is considered a major source for personal exposure to fine particles, because commuters are in direct contact and close to the pollution sources such as vehicles (Rivas et al., 2017). Mobile sources such as vehicles emit different pollutants to the atmosphere, including particulate matter (PM), hydrocarbons (HC), nitrogen oxides (NOx), carbon monoxide (CO), sulphur dioxide (SO2), and greenhouse gases

(e.g. carbon monoxide (CO_2)) (Deng et al., 2015). Every year, air pollution causes 40,000 cases of mortality or more, about half of these cases are associated with the pollutants emitted from motorized transport (Künzli et al., 2000). Hence, people who commute on major roads (i.e. busy roads) can have adverse health effects (Gulliver and Briggs, 2007) which may lead to cardiopulmonary mortality due to traffic-related air pollution (Hoek et al., 2002).

Another source of personal exposure to fine particles is candle burning, which produces black soot that can circulate indoors, hit surfaces and remain on objects (Knight et al., 2001). Lighting candles can elevate the UFP concentrations indoors 5 times (He et al., 2004), and inhaled by indiviuals and cause cardiopulmonary problems (Brook et al., 2004, Dockery et al., 1993, He et al., 2011, Jerrett et al., 2009, Peters et al., 2000, Pope et al., 2002).

The six cognitive domains of the brain that can be assessed using different cognitive tests are: Visual-Spatial, Executive Function, Verbal Fluency, Memory, Attention, and Orientation (Dougherty and Halliday, 2015) (descriptions of the domains are provided in Chapter 2). In earlier years, oral and written tests were used to assess cognitive performance; in recent years many computerized test batteries have been developed to assess different domains of cognition (Bolla, 1991).

This chapter relates to two human activities that can contribute to air pollution, and produce many pollutants including PM. These activities are commuting, and candle burning. Candles are used in many situations, and sometimes on a daily basis, such as religious purposes (e.g. churches), spiritual purposes (e.g. spiritual healing therapies), relaxing... etc. In addition to the importance of candles as a potential

indoor pollution source, they also provide an easy to control source of PM for exposure experiments.

6.2 Aim

To assess the effect of short term personal exposure to air pollution on cognitive performance. The research hypothesizes that personal exposure at short time scales to fine particles has an adverse effect on cognitive performance. This hypothesis is tested under two scenarios: short-term exposure to air pollution due to commuting, and short-term exposure to particulate matter air pollution resulting from candle burning.

6.3 Materials and methodology

6.3.1 Overall methodology

Two projects were carried out to find whether air pollution has an adverse effect on cognitive performance. These are ‘Effects of $PM_{2.5}$ emissions from candle burning on cognitive performance’; and ‘Effects of pollution from commuting on cognitive performance’. The criteria for subjects in both projects were: healthy, non-smoking adults, English first language, non-occupationally exposed to air pollution. 30 subjects were recruited for the first project, and 33 subjects were recruited for the second project. 3 subjects of the second project did not test for the Stroop color and word test, because their first language was not English, but they were recruited because there was enough time and test materials to test 3 more subjects.

An announcement and post were used to find subjects; an announcement poster was distributed in the Geography, Earth, and Environmental Sciences building of the University of Birmingham, and in the main library, an electronic announcement was posted on the my.bham portal website, and letters were sent to random addresses from previous volunteers' databases. Both projects have full ethical approval from the Science, Technology, Engineering and Mathematics Ethical Review Committee (reference number ERN_16-0897) in the University of Birmingham.

Potential subjects responded by e-mail or by contacting the office phone number. They were then sent an e-mail with further information about the research. This information was sent as MS Word document, including a participant information sheet which gave the research information, and a screening questionnaire to be filled in by the potential subjects to eliminate those who did not meet the criteria.

Any further questions by the subjects were answered by e-mail; and they were interviewed if they were eligible. Other forms to be filled in by the eligible subjects included a consent form, and a confounding questionnaire. The latter was to be filled before each test (i.e. pre-exposure, post-exposure), to check for any conditions affecting their performance in the test. Subjects were also informed that they could withdraw from the research if they decided not to proceed with the study, and they received a withdrawal form in advance.

The following information is from the review “Correlation between short and long-term exposure to air pollution and cognitive performance in adults and elderly: A systematic review” (Shehab. et al., n.d.)

A systematic review search was conducted using PubMed, Web of Science, BioOne, ScienceDirect and Bioline, from the period 1960 to mid-2017. 22 studies were found on the correlation between exposure to air pollution and cognitive performance, all having the same criteria: papers in English, healthy subjects, non-occupationally exposed, non-smokers, adults and elderly only. The 22 studies are not all comparable, as each one used different cognition tests, and different pollutant types. 7 out of 22 investigated short-term exposure to air pollution to find its correlation to cognitive performance, and a summary illustrating the main outcomes and limitations of these 7 studies is in Table 2, Chapter 2.

The studies did not take into account confounding factors, only one study considered just alcohol consumption and drugs abuse; two studies included some smokers with the other non-smoker subjects; subjects in all the studies were aware that they were exposed to the pollutant when taking the test, which might include psychological effects on wellbeing (Huppert, 2009, Ryff, 1989, Ryff, 2014). However, in two studies (Driessen et al., 2012, Chuwers et al., 1995), despite being blinded to the pollutants in both studies, subjects in the first study noticed the absence of diesel exposure during non-exposure conditions, and in the second some subjects may have been aware they were exposed to the pollutant when taking the test. Other limitations are shown in Table 2, Chapter 2.

This study is different from the 7 previous studies, as in this study:

- Confounding factors were taken into account and these factors are shown in the confounding questionnaire in Appendix 7,

- The candles were lit when the participant was out of the room, subjects exposed to $PM_{2.5}$ from candles were not aware of the exposure, except one subject. The participants were not aware of the presence of candle burning because the candles were separated using a non-flammable insulation board,

- Inclusion criteria included only subjects who are healthy adults, non-smokers, non-occupationally exposed.

Two papers used pollutants from traffic. Driessen et al., 2012 correlated nanoparticles from diesel engines to cognitive performance, and did not find an effect on cognitive performance. Bos et al., 2013 on the other hand, correlated UFP (0.02-1µm) from traffic to cognitive performance, and found that it had a negative effect on response-inhibition and selective attention, but no effect was found on sustained attention and reaction time.

In this project, subjects were exposed to traffic pollutants from commuting, which included particulate matter (PM_1, $PM_{2.5}$ and PM_{10}), BC, UFP, PNC, NO_x, CO, CO_2, HC, and water vapour. This study is different from both Driessen et al., 2012 and Bos et al., 2013 in using different cognitive tests, except the Stroop Color-Word test which was used by Bos et al., 2013.

Two studies used Stroop Color-Word test. First, Bos et al., 2013, to find the correlation between PM from traffic and cognitive performance in terms of response-inhibition and selective attention. Second, Chuwers et al., 1995, to find a correlation between Methanol vapour and executive function. Some subjects might have been aware they were exposed to the pollutant when taking the test, also some subjects were smokers. Only Bos et al (2013) found a negative effect on response-inhibition and selective attention, neither considered confounding factors that may affect subject performance during test. Chuwers et al (1995) study also used ruff 2 and 7, but the researcher cancelled the results as they were unacceptable; none of the studies used MMSE test.

Both projects in the present study used MMSE, and used different methodologies in exposure to pollutants. Cognitive tests are limited because other tests should be used by professional psychologists, or the researcher should be supervised by professional psychologists. But the tests in this research can be used by other researchers from different departments.

The outcome of the projects in this study will add new information for the cognitive psychology field, and to epidemiology, which can be used in addressing the pollutants sources that can affect the cognitive performance, and taking them into account when patients report having problems in their cognitive performance.

Table 2 in Chapter 2 shows a summary of the main previous studies outcomes of short-term effects of air pollutants on cognitive performance, and Table 3 in chapter 2 shows Characteristics of these studies.

6.3.2 Materials

6.3.2.1 Cognitive Tests and Their Description

All the instructions for using the test including testing procedures, requirements, instructions given to the subjects, scoring, are provided in the test manuals (Folstein et al., 2001, Golden and Freshwater, 2002, Ruff and Allen, 1996). No copies of tests themselves or the detailed instructions are provided in this report for copyright reasons. All tests are paper and pencil or pen tests. Verbal instructions are given to the subjects before the tests in both pre-exposure and post-exposure. Subjects who test successively may perform better results, therefore in this research the subjects are allowed not less than one day to repeat the test to reduce the effect of practising. All tests scorings consider the age and education of the subjects.

Mini-Mental State Examination (MMSE)

The test is a global assessment of an individual's cognitive functioning, including memory, attention, orientation, and language, to indicate overall cognitive ability. The test consists of a set of 11 questions and tasks, the subject is asked to answer and do, as follows:

Orientation to time: Questions about the year, season, month of the year, day of the week, and date, to assess their orientation to time.

Orientation to place: Questions about current place, to assess the subject's orientation to place.

Registration: Subject is asked to repeat 3 words after the researcher says them, to assess the ability to learn and retain 3 unrelated words, and the level of alertness and attentiveness.

Attention and calculation: Mathematical question about subtracting 7 from 100, then subtracting 7 from the answer, repeated 4 times (5 answers in total).

Recall: The subject says the 3 words he/she repeated in the registration question, to assess the ability to recall the words learnt in the registration question.

Naming: Two questions to name any objects the researcher points to, such as pen, pencil, keys, etc.), to assess the ability to recognize and name 2 common objects.

Repetition: The subject is asked to repeat a sentence after the researcher says it, to assess the ability to repeat exactly a series of unrelated words that are not often said together.

Comprehension: The subject is asked to listen to and follow the researcher's instructions to take a white paper with their right hand, fold it in half, and put it anywhere the researcher says, like on the table or the floor, this assesses the ability to attend to, understand and perform a complex three-stage command.

Reading: The test has a paper with the sentence "CLOSE YOUR EYES". The researcher asks the subject to read and do what the paper says, to assess the ability to read and understand a simple sentence.

Writing: On a blank page, the subject should write a sentence that has both subject and verb, to test the ability to write a sentence.

Drawing: The test has a drawing of two intersecting pentagons, and the subject is asked to copy the design on a blank paper, to assess the visuospatial ability. Materials used for this test are the test booklet and a pencil.

Stroop color and word test - adult version

The test consists of three pages; each one has 100 items, presented in five columns of 20 items.

The first page is called the Word page, where the items are words written in black, these are “RED”, “BLUE”, and “GREEN”, arranged randomly. Here the subject must read the words.

The second page is called the Color page, which has colored items presented as XXXX written in either red, blue, or green. Here the subject must say the color of the item.

The third page is called the Color-Word page, that has colored words “RED”, “BLUE”, and “GREEN”, arranged randomly, written in either red, blue, or green ink. Here the subject must say the ink’s color of the item, not the word.

The T-score for the "Word" page reflects the motor speech/reading sub-domain. The T-score of the "Color" page also reflects motor speech in addition to intelligence, and the T-score for the color-word page is interpreted relative to the Color and Word scores, and thus is the Interference score. The interference t-score reflects the executive function; it doesn’t necessarily mean the subject has a problem with executive functioning if they have a low Color-Word score, they could also have a low Word score, which might mean that they have a problem reading, and thus isn’t a reflection of executive functioning.

Each subject was tested individually in a quiet room. Once the subject is given the test, the researcher gives the instructions before each page, and the same instructions are given before each test (i.e. Pre-exposure and post-exposure).

For each page, the subject must read the items out loud as fast as they can, starting from the top of the first column, and within the 45 seconds between the researcher saying “start” and “stop”. If the subject finishes all the items of the page before the time is up, he/she should start over from the first word of the first column, and continue reading until the end of the time. The subject circles the last word he says it after hearing “stop”, and writes a small ‘1’ next to the circle in case he/she repeats the words, so the researcher takes it into account when analysing the results.

The materials used for this test are the test booklet, pencil, and stopwatch.

Ruff 2 and 7 Selective Attention Test

This is used to measure two aspects of visual attention, sustained attention, and selective attention. Sustained attention is the ability to concentrate on one particular task, and keep a consistent performance level over a continuous period of time, while ignoring distractors. Selective attention on the other hand is the ability to select relevant targets while neglecting distractors (Eysenck and Keane, 2013, Ruff et al., 1992, Ruff and Allen, 1996, Stevens and Bavelier, 2012).

Sustained attention is assessed by two variables. These are Total Speed, which is the total number of correct targets identified during the assigned five minutes duration; and Total Accuracy, which is the number of identified targets during the assigned five minutes duration divided by the number of possible targets (Messinis et al., 2007, Ruff and Allen, 1996).

Selective attention is assessed by two types of distractor conditions. The first is the Automatic Detection, where the target digits, which are the numbers 2 and 7, are embedded in distractors which are alphabetic; it is called automatic because the numbers 2 and 7 are visibly and clearly a different stimulus category from the alphabetical distractors (Ruff and Allen, 1996). The second is the Controlled search, where both targets (i.e. 2 and 7) and distractors are numbers and belong to the same stimuli category, hence selecting the target requires working memory involvement, which is effortful and resource limited (Logan, 1988, Ruff and Allen, 1996).

The test consists of a series of 20 trials (10 Automatic Detection trials and 10 Controlled Search trials). Each trial takes 15 seconds; hence the total test takes 5 minutes. The subject should cross out all the 2's and 7's as quickly as possible, trying not to miss any, starting from left to right. They start over in the next series every 15 seconds when they hear the word 'next', until the 5 minutes are finished, when the word 'stop' is heard.

The materials used for this test are the test booklet, stopwatch, and red or bright pen to make it clear for the researcher when detecting the hits for calculation.

6.3.3 Effects of $PM_{2.5}$ Emissions from Candle Burning on Cognitive Performance

Sample selection: two announcements were created to seek volunteers, the first was a flyer distributed in the Geography, Earth, and Environmental Sciences building and sent in letters for mass mailing, and the second was an announcement through the my-bham website portal, both announcements are shown in Appendix 7.

The criteria include healthy adults, non-smokers, English first language, and not suffering from any factor affecting cognitive performance.

After the screening questionnaire, potential subjects were given an information sheet (appendix 7) to explain the project and their role, in addition to meeting to answer further questions if they have any.

After recruitment, subjects were given a consent form to be signed by them, and by the researcher and the supervisor, and a withdrawal form in case they no longer wanted to proceed with the project; both forms are shown in Appendix 7.

Table 1 shows numbers of volunteers who responded according to recruitment method.

Room conditions: subjects performed the 3 cognitive tests in a quiet room with dimensions 3.17m^3 x 3.10m^3 x 2.5m^3, with door and windows closed. A comfortable chair and desk were provided for the subject during the experiment. The room without candle burning already contains particles from ambient outdoor particles that enter the room through doors, windows, and other openings. The sources of these particles can be from car exhausts, construction work (World Health Organisation), and may include soot created by burning candles in the room and deposits on the barrier board, or other items like the computer in the room which can be a source of particles (Knight et al., 2001).

Instruments and materials: TSI instrument (Optical Particle Sizer 3330 (OPS): it is a portable light weight instrument that measures particle concentration (from 0 to 3,000 particles/cm^3) and particle size distribution, with size range from 0.3 - 10 μm, and size resolution < 5% at 0.5 μm. Particle mass is estimated from the measured particle

size. The TSI 3330 is an optical particle sizer, which estimates the size of the particles by measuring the light that is scattered from them. The algorithm used for this estimation makes standard assumptions about the particles, first that the particle density is 1 g/cm^3, second that the particles are spherical.

The instrument can be used for different purposes including monitoring and controlling emissions, monitoring outdoor environment and work places, monitoring indoor air quality. In this project, it is used to determine particulate matter (PM) concentrations including $PM_{2.5}$, which is the pollutant of concern in this research. The data are shown directly in the instrument screen, and can be saved from the instrument using a USB stick, and downloaded by the Aerosol Instrument Manager® software for Optical Particle Sizer (OPS) Spectrometers.

A 9-inch fan was used to assure homogeneity of air pollutants within the study room, placed 75 cm away from the candles on a table. The table was obscured from participants using a non-flammable insulation board so the subject was not aware if the candles were lit or not. Only two participants noticed and publicly stated that candles were burning, one from the pilot experiment, which was not taken into account in the study, and the second subject asked when she smelled candle burning, but she was not answered. She also mentioned that she has a high sensitivity to smell. Other subjects did not comment if they have noticed burning smell, however, this does not rule out that they could detect differences. Half of the subjects were tested first with candle burning and then without exposure to candle burning, and the other half the other way round.

The candles used vary in type (i.e. Paraffin, beeswax, stearin), due to market availability, all with cotton wick. Different numbers of the same candle type were used in each test, because the PM concentrations vary from candle burning and concentrations can be shown directly in the instrument screen.

Pilot experiment: before the start of sampling and testing, a pilot experiment was performed to ensure that all experiment conditions were in order i.e.

- that questions including confounding questionnaire were understood;
- whether the subject had difficulties that could be avoided in the sampling;
- that all the tests, instructions and forms were clear;
- that room conditions were suitable for 1 hour of testing i.e. it was possible for the subject to be comfortable with no distractions. Furthermore, the room had a window and adequate ventilation to allow for the removal of PM generated from the candle in between sampling.

Only one change was made: the fan needed to be on in both post-exposure and pre-exposure experiments, to create the same conditions of background sound and air homogeneity. Measurements were taken from different locations in the room to assure homogeneity of concentration; the locations included where the subject sat to take the test, and at the level of their breathing area.

6.3.4 Effects of Pollution from Commuting on Cognitive Performance

Subjects performed the 3 cognitive tests in a room with dimensions 3.17m^3 x 3.10m^3 x 2.5m^3. For the pre-exposure test, the subject should sit in the room with windows and door closed for 1 hour, this is to eliminate any pollution from outside. After 1 hour, the

subjects performed the 3 tests. As for the post-exposure test, the subject performed the tests directly after commuting. Pollutants in the commuting part of the project were not measured. However, as explained in previously, exposure from outdoors is higher than indoors, also it can be estimated from pre-exposure data in the candle burning experiment, or from the cohort study in Chapter 4.

6.4 Statistical methodology and data analysis

The sample sizes were 33 in the Commuting project and 30 in the $PM_{2.5}$ from candle burning project; both numbers are large enough and sufficient to provide useful test results (Chassan, 1979, Roscoe, 1975, Minitab, 2017). None of the volunteers withdrew from the project.

Minitab version 17.1.0 software was used to perform the statistical analysis, used to extract the results of these projects, in addition to Microsoft Excel 2016 statistical software used to conduct medians. A Kolmogorov-Smirnov normality test for the pre-exposure and post-exposure was used to check data for normality, a two-sided paired t-test was performed comparing the mean pre-exposure and post-exposure scores to test hypothesis. Results are illustrated by bar charts and tables from Minitab output. $PM_{2.5}$ mass concentrations were obtained from Aerosol Instrument Manager® software for Optical Particle Sizer (OPS) Spectrometers, as explained in section 6.3.3. under ‘Instruments and materials’.

T-scores for each test were obtained from calculations provided in the manuals. Mean, median, and standard deviation of t-scores and $PM_{2.5}$ concentrations were obtained from Excel software version 2016.

The Confounding questionnaire consists of 32 questions grouped into 6 parts, 5 parts concern confounding factors that may affect test performance, and 1 part concerns socio-economic information. This information was not tested against the tests results because is it not one of the research objectives, but age and education were taken into account in scoring all the tests, and can be used in other papers and studies in future. Questions about confounding factors cover noise exposure, sleeping problems, emotional state, and caffeine consumption. Detailed questions are shown in the confounding questionnaire in Appendix 7.

6.5 Results

6.5.1 Recruitment of subjects

- 30 subjects were recruited for the ‘Exposure to $PM_{2.5}$ from candle burning’ project, and 33 subjects for the ‘Exposure to pollutants from commuting’ project.
- There was a high response from the announcement through my-bham portal website (University of Birmingham online information hub), and very low response from the mass mailing. All information is shown in Table 9.

Table 9: Number of Volunteers Response According to Recruitment Method

Method	Number of announcements sent	Project	Number of respondents*	Potential subjects*	Subjects meet criteria-	Recruited*
Mass mailing	160 letters	Commuting	1	1	1	1
		$PM_{2.5}$ from candle burning	2	2	2	2
Announcement leaflet in the University	2 leaflets	Commuting	14	11	10	3
		$PM_{2.5}$ from candle burning	0	0	0	0
My bham website announcement	2 times	Commuting	143	73	64	22
		$PM_{2.5}$ from candle burning		70	66	27
Through colleagues	5	Commuting	5	4	4	4
		$PM_{2.5}$ from candle burning	1	1	1	1
Volunteer's friends and colleagues	3	Commuting	6	3	3	3
		$PM_{2.5}$ from candle burning	1	1	1	1

*Number of respondents are the subjects who responded to different announcements, and were sent a screening questionnaire to be filled and the return of the forms was expected.
*Potential subjects are the number of volunteers who filled the screening questionnaires and sent them back
*Recruited are the subjects who agreed to participate to the project

- Some of the subjects who met the criteria did not reply to their e-mails

- Subjects who met the criteria but responded after the recruitment was completed were sent an e-mail announcing the completion of recruitment

6.5.2 Subjects Sampling Routine and Candles Used

The exposure routine, candle types and numbers are shown in Table 10. The average concentrations during candle burning and without candle burning are shown in Table 13.

Table 10: Exposure routine and candle types and numbers

ID	Exposure routine		Candle type	Candle numbers
1	Pre-exposure	Post-Exposure	Paraffin	9
2	Pre-exposure	Post-Exposure	beeswax	9
3	Pre-exposure	Post-Exposure	Paraffin	9
4	Pre-exposure	Post-Exposure	beeswax	9
5	Pre-exposure	Post-Exposure	beeswax	9
6	Pre-exposure	Post-Exposure	Paraffin	9
7	Pre-exposure	Post-Exposure	Paraffin	9
8	Post-Exposure	Pre-exposure	Beeswax	9
9	Pre-exposure	Post-Exposure	Stearin	8
10	Pre-exposure	Post-Exposure	Paraffin	9
11	Pre-exposure	Post-Exposure	Stearin	8
12	Pre-exposure	Post-Exposure	Paraffin	9
13	Pre-exposure	Post-Exposure	Paraffin	9
14	Post-Exposure	Pre-exposure	Paraffin	9
15	Post-Exposure	Pre-exposure	Paraffin	9
16	Pre-exposure	Post-Exposure	Stearin	6
17	Post-Exposure	Pre-exposure	Paraffin	9
18	Pre-exposure	Post-Exposure	Stearin	8
19	Post-Exposure	Pre-exposure	Stearin	6
20	Post-Exposure	Pre-exposure	Stearin	8
21	Post-Exposure	Pre-exposure	Stearin	6
22	Post-Exposure	Pre-exposure	Paraffin	9
23	Post-Exposure	Pre-exposure	Stearin	6
24	Pre-exposure	Post-Exposure	Stearin	6
25	Post-Exposure	Pre-exposure	Stearin	6
26	Post-Exposure	Pre-exposure	Stearin	6
27	Post-Exposure	Pre-exposure	Stearin	6
28	Post-Exposure	Pre-exposure	Stearin	6
29	Post-Exposure	Pre-exposure	Stearin	6
30	Post-Exposure	Pre-exposure	Stearin	6

6.5.3 Questionnaire Results

Characteristics of subjects: the majority of the subjects were aged under 24 years, and were students (60.61%, 73.33% for both projects, commuting and candle burning respectively). In terms of education, most of the subjects for the commuting project were post graduates (36.36%), followed by both high school and an undergraduate/ professional qualification (27.27%). Most of the subjects in the candle burning project were high school (33.33%), followed by undergraduate/ professional qualification (26.67%). All information is shown in Table 11.

Table 11: characteristics of subjects

	Exposure to pollutants from commuting (n=33)	**Exposure to $PM_{2.5}$ from candle burning (n= 30)**
Gender (male/female)	15/18	10/20
Age %		
25-35 years old	21.21	16.67
36-45 years old	15.15	6.67
Over 56 years	9.09	6.67
Under 24 years	54.55	70
Weight mean (SD)	66.9 (14.9)	66.8 (16.1)
Height (mean ± SD)	171 (9.6)	167 (10.7)
Education %		
-Diploma/technical qualification	3.03	6.67
-High School	27.27	33.33
-PG degree	36.36	13.33
-Secondary School	6.06	20
-UG degree/professional qualification	27.27	26.67
Occupational position %		
-Higher managerial, administrative and professional occupations	30.30	20
-Intermediate occupations	6.06	3.33
-Routine and manual occupations	3.03	3.33
-Student	60.61	73.33

6.5.4 Effects of $PM_{2.5}$ Emissions from Candle Burning on Cognitive Performance

The Minitab output for this experiment is shown in Appendix 8. Summary of results including mean, median, standard deviation (SD), Kolmogorov-Smirnov p-value, and t-test p-value are shown in table 12. $PM_{2.5}$ ($\mu g/m^3$) concentration average before and after exposure are shown in table 13. 30 subjects were tested for this project.

Table 12: T-scores results for cognitive tests from exposure to $PM_{2.5}$ ($\mu g/m^3$) emissions from candle burning on cognitive performance before and after exposure

Test	Exposure time	mean	SD*	median	K-S* p-value	t-test p-value
MMSE	Pre-exposure	47.9	15.9	56	>0.15	0.011
	Post-exposure	40.3	16.7	43		
Stroop Word	Pre-exposure	49.1	12.3	49.5	>0.15	0.652
	Post-exposure	48.3	14	51.5		
Stroop Color	Pre-exposure	50.4	8.6	51.5	>0.15	0.800
	Post-exposure	50	9.8	50.5		
Stroop Color-Word	Pre-exposure	58.7	8.9	58.5	0.096	0.658
	Post-exposure	59.3	9.4	59		
Stroop Interference	Pre-exposure	60.7	8.4	59.5	0.109	0.647
	Post-exposure	61.3	8	60		
Ruff 2&7 (Sustained attention-speed)	Pre-exposure	53.5	11.5	54.5	>0.15	0.628
	Post-exposure	52.9	12.1	52.5		
Ruff 2&7 (Sustained attention-accuracy)	Pre-exposure	47	10.6	51	>0.15	0.440
	Post-exposure	45.6	11.1	48.5		
Ruff 2&7 (Selective attention-ADS*)	Pre-exposure	52.5	10.7	53	>0.15	0.378
	Post-exposure	51.5	11.3	51.5		
Ruff 2&7 (Selective attention-ADA*)	Pre-exposure	47.8	10.1	51.5	0.045	0.228
	Post-exposure	45.7	10.4	49.5		
Ruff 2&7 (Selective attention-CSS*)	Pre-exposure	51.2	12	51	>0.15	0.623
	Post-exposure	50.6	12.3	51		
Ruff 2&7 (Selective attention-CSA*)	Pre-exposure	46.7	12.2	50.5	>0.15	0.862
	Post-exposure	46.3	13.2	50		

*K-S: Kolmogorov-Smirnov
*SD: standard deviation
*ADS: Automatic detection speed
*ADA: Automatic detection accuracy
*CSS: Controlled search speed
*CSA: Controlled search accuracy

Table 13: Average $PM_{2.5}$ concentration during candle burning and without candle burning

Exposure type	Mean ± (SD)	Median
$PM_{2.5}$ Total Conc. (µg/m³) post-Exposure	41.4 ± (46.1)	27
$PM_{2.5}$ Total Conc. (µg/m³) pre-Exposure	1.6 ± (1.3)	1.234

A two-sided paired t-test was performed comparing the mean pre-exposure and post-exposure scores of various tests with the following hypotheses:

H0: Exposure to $PM_{2.5}$ from candle burning has no effect on cognitive performance (i.e. the mean scores are equal)

H1: Exposure to $PM_{2.5}$ from candle burning has an effect on cognitive performance (i.e. the mean scores are not equal)

6.5.4.1 MMSE test

From Kolmogorov-Smirnov normality test for difference in scores, p-values indicate the scores appeared to be normally distributed.

The p-value from this test was 0.011, providing strong evidence against H0, and hence in favour of H1. Given the mean of the difference was positive, this provided strong

evidence that exposure to $PM_{2.5}$ from candle burning had an adverse effect on cognitive performance in terms of cognitive functioning, where the $PM_{2.5}$ exposure during the candle burning experiment was also seen to be significant. The null hypothesis was rejected at the 5% significance level, in favour of the alternative hypothesis.
(see Table 10).

- Correlation between $PM_{2.5}$ concentrations and MMSE scores

To further investigate the effect of candle burning on cognitive performance, the effect of $PM_{2.5}$ mass concentration upon cognitive performance was investigated. A regression analysis was performed to determine if the effect on cognitive functioning is due to increase of $PM_{2.5}$ from candle burning, with the following hypothesis:

H0: Exposure to $PM_{2.5}$ from candle burning has no effect on cognitive performance (i.e. the mean scores are equal)

H1: Exposure to $PM_{2.5}$ from candle burning has an effect on cognitive performance (i.e. the mean scores are not equal).

The p-value for the line "Regression" is 0.610. The null hypothesis is that the regression coefficient (i.e. the slope of the line) is zero; in other words, no relationship between the variables. This p-value provides no evidence to reject this. There are some points noted as unusual observations, either because their residuals are large, or one of t-score/$PM_{2.5}$ difference is extreme (e.g the $PM_{2.5}$ difference of participant 7 is very high. compared to most others). Figure 15 shows the results of the regression line plot.

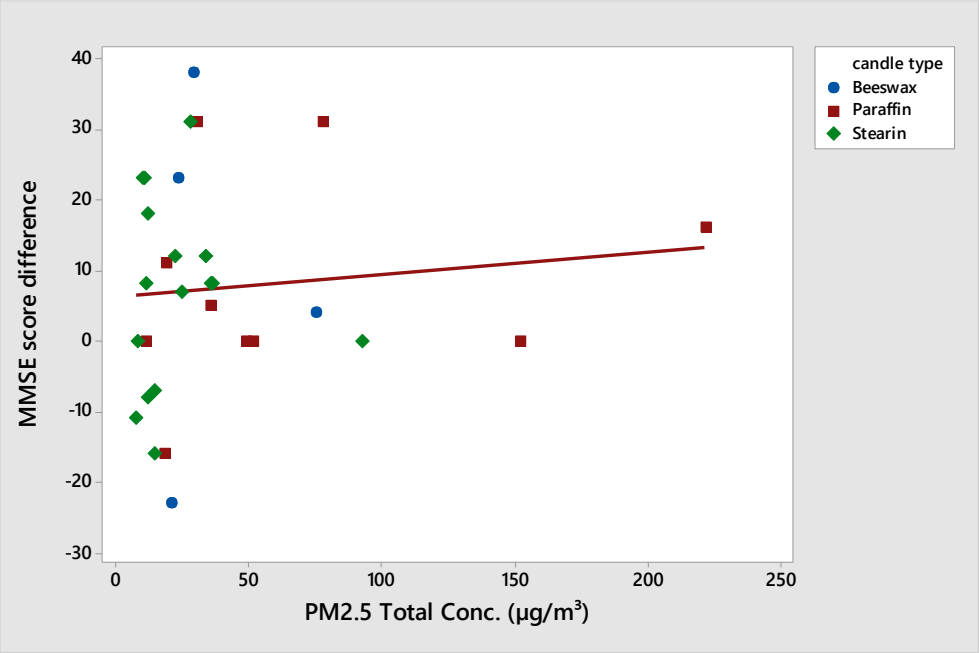

Figure 15: Correlation between MMSE t-score difference and $PM_{2.5}$ difference fitted line plot

The results conclude that there is no statistically significant relationship between t-score difference and $PM_{2.5}$ difference. However, when comparing t-scores according to the WHO 24-hour guidelines for $PM_{2.5}$ concentrations (< or >25 µg/m³), it shows that t-scores decreases when the $PM_{2.5}$ is >25 µg/m³. Figure 16 shows the correlation between t-scores and $PM_{2.5}$ concentrations.

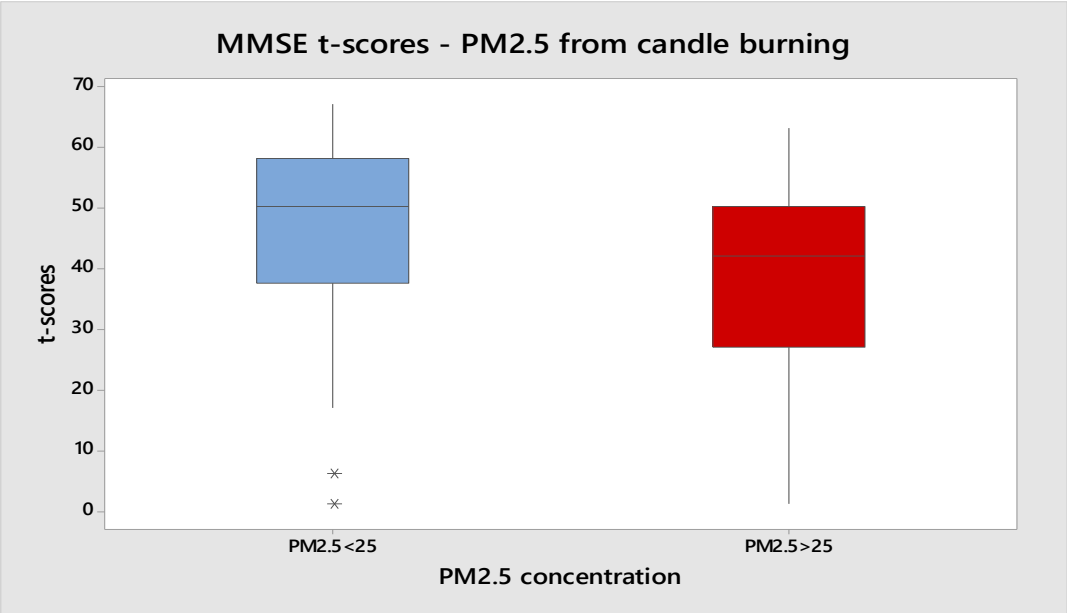

Figure 16: MMSE t-scores and exposure to $PM_{2.5}$ < 25 (µg/m³), and to $PM_{2.5}$ > 25 (µg/m³) from candle burning

We hypothesize that MMSE t-scores after exposure to $PM_{2.5}$ > 25 µg/m³ indicate a decline in cognitive performance. A Kolmogorov-Smirnov normality test for the t-scores after exposure to $PM_{2.5}$ < 25 µg/m³, and after exposure to $PM_{2.5}$ > 25 µg/m³ was used to check data for normality. The hypothesis is when p-value is less than 0.05 we reject the null hypothesis (the null hypothesis being the data are from a normal distribution). The alternative hypothesis is if p-value is lower than 0.05 it provides evidence the data is not from a normal distribution. Minitab version 18 is used in this analysis.

The results show that p-value for group t-scores after exposure to $PM_{2.5}$ < 25 µg/m³ is > 0.010, and after exposure to $PM_{2.5}$ > 25 µg/m³ is > 0.029. This indicates that the null hypothesis is rejected (i.e. scores appeared to be not normally distributed). Hence, the Mann-Whitney test was performed comparing the medians of the two groups' scores with the following hypotheses:

H0: Exposure to $PM_{2.5}$ < 25 µg/m³ has no effect on cognitive performance (i.e. the medians are equal)

H1: Exposure to $PM_{2.5}$ > 25 µg/m³ has an effect on cognitive performance (i.e. the medians are not equal).

The results show the p-value for not adjusted for ties is 0.045, and for adjusted for ties is 0.041. The null hypothesis is rejected. The data indicates the median measurement from t-scores after exposure to $PM_{2.5}$ < 25 µg/m³ is (median= 50) higher than after exposure to $PM_{2.5}$ > 25 µg/m³ (median= 42). This finding supports the hypothesis that exposure to $PM_{2.5}$ > 25 µg/m³ leads to a decline in cognitive performance.

(See Appendix 8 for the outputs).

"A tie occurs when the same value is in both samples. If your data has ties, Minitab displays a p-value that is adjusted for ties and a p-value that is not adjusted. The adjusted p-value is usually more accurate than the unadjusted p-value. However, the unadjusted p-value is the more conservative estimate because it is always greater than the adjusted p-value for a specific pair of samples." (Minitab Express Support).

6.5.4.2 Stroop Word-Color test

From Kolmogorov-Smirnov normality test for difference in scores, p-values indicate the scores appeared to be normally distributed, for all sections of the test.

The p-value from all sections of the (Word, Color, Color-Word, Interference) provide no evidence against H0. In other words, the data provide no evidence of a difference between pre- and post-exposure mean scores, hence the null hypothesis was not rejected at the 5% significance level.

(see Table 10).

6.5.4.3 Ruff 2 and 7 test

From Kolmogorov-Smirnov normality test for difference in scores, the p-value indicates the scores appeared to be normally distributed in all parts of the test, except selective attention - the automatic detection accuracy, where p-value=0.045, which indicates there was evidence the scores were not normally distributed (rejected at 5% significance). The p-value from all parts of this test (sustained attention: speed; accuracy, selective attention: automatic detection speed; automatic detection accuracy; controlled search speed; controlled search accuracy) provide no evidence against H0. In other words, the data provide no evidence of a difference between pre- and post-exposure scores, hence the null hypothesis was not rejected at the 5% significance level.
(see Table 10).

6.5.5 Effects of Pollution from Commuting to Cognitive Performance

The Minitab output for this experiment is shown in Appendix 8. Summary of results including mean, median, standard deviation (SD), Kolmogorov-Smirnov p-value, t-test p-value are shown in Table 14. 33 subjects were tested in this project.

Table 14: T-scores results for cognitive tests from exposure to PM from commuting on cognitive performance before and after exposure

Test	Exposure time	mean	SD*	median	K-S* p-value	t-test p-value
MMSE	Pre-exposure	49.6	9.5	50	0.02	0.008
	Post-exposure	41.9	15.9	50		
Stroop Word	Pre-exposure	44.6	12.4	45	0.031	0.391
	Post-exposure	47.1	12.2	48		

Stroop Color	Pre-exposure	47.1	12.3	45	>0.15	0.794
	Post-exposure	46.8	10.8	45		
Stroop Color-Word	Pre-exposure	55.9	14.4	55.9	>0.15	0.384
	Post-exposure	54.4	11.1	56		
Stroop Interference	Pre-exposure	60.1	9.0	59	>0.15	0.473
	Post-exposure	59.1	7.3	57		
Ruff 2&7 (Sustained attention-speed)	Pre-exposure	55.3	13.5	55	0.044	0.232
	Post-exposure	53.4	13.4	53		
Ruff 2&7 (Sustained attention-accuracy)	Pre-exposure	51.1	6.6	53	0.035	0.530
	Post-exposure	50.2	8.0	53		
Ruff 2&7 (Selective attention-ADS*)	Pre-exposure	56.2	13.2	54	>0.15	0.006
	Post-exposure	52.6	12.1	53		
Ruff 2&7 (Selective attention-ADA*)	Pre-exposure	51.9	3.8	52	0.047	0.634
	Post-exposure	51.4	6.0	53		
Ruff 2&7 (Selective attention-CSS*)	Pre-exposure	51.8	15.5	52	>0.15	0.300
	Post-exposure	50.3	15.2	50		
Ruff 2&7 (Selective attention-CSA*)	Pre-exposure	50.3	10.6	53	0.090	0.591
	Post-exposure	49.2	11.5	52		

*K-S: Kolmogorov-Smirnov
*SD: standard deviation
*ADS: Automatic detection speed
*ADA: Automatic detection accuracy
*CSS: Controlled search speed
*CSA: Controlled search accuracy

A two-sided paired t-test was performed comparing the mean pre-exposure and post-exposure scores of various tests with the following hypotheses:

H0: Exposure to pollutants from commuting has no effect on cognitive performance (i.e. the mean scores are equal)

H1: Exposure to pollutants from commuting has an effect on cognitive performance (i.e. the mean scores are not equal)

6.5.5.1 MMSE test

From Kolmogorov-Smirnov normality test for difference in scores, p-value=0.02, which indicated there was evidence the scores were not normally distributed (rejected at 5% significance).

The p-value from this test was 0.008, providing very strong evidence against H0, and hence in favour of H1. Given the mean of the difference was positive, this provided strong evidence that exposure to pollutants from commuting had an adverse effect on cognitive performance in terms of cognitive functioning, which is consistent with the results from exposure to $PM_{2.5}$ from candle burning. The null hypothesis was rejected at the 5% significance level, in favour of the alternative hypothesis.

(see Table 12).

6.5.5.2 Stroop Word-Color test

From Kolmogorov-Smirnov normality test for difference in scores, p-value indicate the scores appeared to be normally distributed in all parts of the test, except the “word” scores, where p-value=0.031, which indicated there was evidence the scores were not normally distributed (rejected at 5% significance).

Similar to the results shown in the previous project of the effect of $PM_{2.5}$ from candle burning on cognitive performance, here also the p-value from all parts of the test (Word, Color, Color-Word, Interference) provide no evidence against H0. In other words, the data provide no evidence of a difference between pre- and post-exposure mean scores, hence the null hypothesis was not rejected at the 5% significance level.

(See Table 12).

6.5.5.3 Ruff 2 and 7test

From Kolmogorov-Smirnov normality test for difference in scores, p-value indicate the scores appeared to be normally distributed in all parts of the, except the sustained attention both “speed” and “accuracy”, and selective attention “automatic detection accuracy”.

The p-value from this test provide no evidence against H0 in all parts except selective attention - automatic detection speed, where the p-value from this test was 0.006, providing very strong evidence against H0, and hence in favour of H1, this is a contrast with the results from exposure to $PM_{2.5}$ from candle burning. Given the mean of the difference was positive, this provided strong evidence that exposure to pollutants from commuting had an adverse effect on cognitive performance in selective attention in terms of automatic detection speed, hence the null hypothesis was rejected at the 5% significance level, in favour of the alternative hypothesis.

As for the other parts, the data provide no evidence of a difference between pre- and post-exposure scores, hence the null hypothesis was not rejected at the 5% significance level.

(See Table 12).

6.6. Discussion

The study results provide strong evidence that short-term exposure to commuting and candle burning reduces the individual’s cognitive performance in terms of cognitive functioning (Figure 17). Decline in cognitive functioning can affect the memory and

attention, which can result in some problems such as forgetting, inability to recall, difficulty in decision making, difficulty in performing in school exams. In addition, exposure to commuting had an adverse effect on cognitive performance in selective attention in terms of automatic detection speed.

All other results show no statistical difference between pre-exposure and post-exposure for both projects. This indicates that there is no effect from short-term exposure to pollutants from commuting and $PM_{2.5}$ from candle burning on cognitive performance, in terms of motor speech/reading sub-domain (Language domain), intelligence, executive function; sustained attention and selective attention and their subdomains, except as mentioned above. However, results from exposure to $PM_{2.5}$ from candle burning appear to diverge from commuting with respect to the selective attention result. This is likely because the pollutants from commuting or outdoor ambient air (Deng et al., 2015, World Health Organisation) are different to those produced by candle burning. There is a mixture of urban pollutants (e.g. PM, NO_x, O_3) whereas the candle burning results in predominantly PM pollution. The pollutants from outdoor ambient air have an adverse effect on selective attention in terms of automatic detection speed; or, since the pollutant loadings from different activities (i.e. commuting, candle burning) produce different pollutants, and only $PM_{2.5}$ concentrations from candle burning was estimated, then it might be the concentrations of pollutants from commuting were higher than concentrations of $PM_{2.5}$ from candle burning, and these concentrations affect the selective attention in terms of automatic detection speed.

The finding of this study confirms the outcome result from Bos et al. (2013) study which also used Stroop color and word test, which is exposure to PM has an adverse effect on

cognitive performance in terms of executive function, although their study was on UFP with different concentrations to this study (Table 2, Chapter 2). However, the measurements in each study are proxies for the measurements in the other study, since UFP is a reasonable predictor of $PM_{2.5}$, and vice versa.

Although the Amitai et al. (1998) study used different tests and methodology, the study findings provide evidence that exposure to CO from kerosene stoves is associated with cognitive impairment (Table 2, Chapter 2). Since an urban background includes CO from different sources such as restaurants and car exhausts (World Health Organisation), and candle burning can increase the CO concentration in the room (Knight et al., 2001), then this also supports this study's findings, that short-term exposure to air pollutants from some activities such as commuting and candle burning can affect cognitive performance. This can also include other activities mentioned in the cohort study like cooking, travelling in vehicles, walking and running outdoors, and being in microenvironments such as in vehicles and outdoors.

One limitation of this study was that one of the subjects may have noticed the presence of candles, and although when she asked if the candles were lit during the experiment the answer was not given to her, maybe she assumed that candles were lit, which may affect her results (Huppert, 2009, Ryff, 1989, Ryff, 2014). Also, for the commuting project, subjects are aware when the exposure was occurring because of the nature of exposure sampling. Portable sensors to measure airborne pollutants were not used in the exposure to airborne pollutants from the commuting project because of time limitations; however, exposure can be estimated by looking at the data of the cohort study in this thesis which include both central site exposure and personal exposure. By

looking at pre-exposure results from the candle burning experiment, in all cases, as explained before, the amount of pollutants from outdoors is higher than indoors, for the same amount of time.

Although statistical analysis shows no significant effect of pollution on cognitive performance in majority of the tests, this does not mean that all subjects before exposure performed better or had the same t-scores than after exposure, some of the subjects had lower or same t-scores after exposure. (see figure 17)

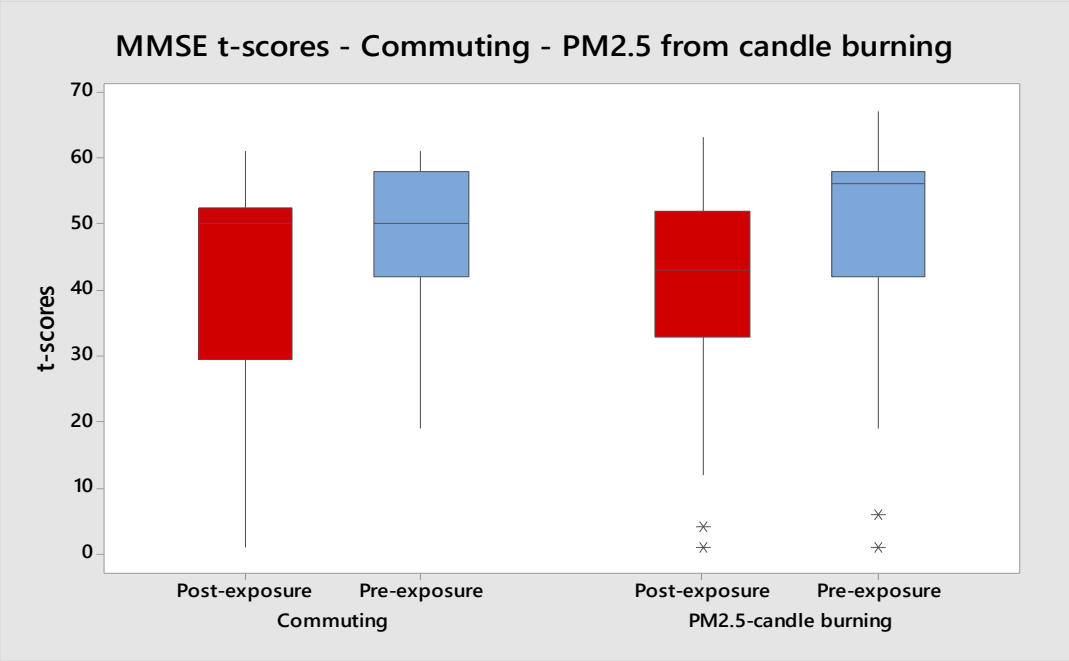

Figure 17: Correlation between MMSE t-scores and exposure to commuting, and $PM_{2.5}$ from candle burning

6.7 Conclusions and recommendations

This is the first study that investigates human exposure to airborne pollutants and its effect on cognitive performance at short-term level on healthy adults, considering confounding factors, and using MMSE and Ruff 2 and 7 cognition tests. The study

results present strong evidence that short-term exposure to pollutants from commuting and $PM_{2.5}$ from candle burning reduces the individual's cognitive functioning in terms of cognitive functioning. The duplication of this result in both the candle burning and commuting experiments provides solid evidence that short term exposure to $PM_{2.5}$ can cause cognitive impairment.

Furthermore, commuting had an adverse effect on cognitive performance in selective attention in terms of automatic detection speed. This effect may be due to urban air pollution exposure, but a lack of statistical difference in the candle burning experiment suggests that it is not due to $PM_{2.5}$ exposure, or at least not exposure to the composition of $PM_{2.5}$ that is generated by candle burning. Other effects of commuting, other than exposure to air pollution, may also play a role, for example exposure to noise pollution.

Recommendations

This study provides evidence that short-term exposure to airborne pollutants has an adverse effect on cognitive performance. Further studies should be done to provide studies that can be comparable, and to avoid the limitations that occur in this study, such as using tests that generate direct and more accurate results for cognitive impairments, like using the Cognitive Assessment Battery (CAB), along with other tests (e.g. MMSE test, Stroop color and word test. etc.) (Nordlund et al., 2011). In the future, the use of portable sensors to measure pollutants from activities such as commuting and comparing them with cognitive tests scores could provide more evidence that the results appear to be positive.

CHAPTER 7: CONCLUSION

This thesis presents the first study to assess personal exposure to air pollutants including BC, $PM_{2.5}$, and UFP, that used modern high temporal resolution sensors to systematically compare concurrently data for personal exposure to those measured at the central sites and at the subjects' houses. Moreover, it presents the first study to assess the effect of personal short-term exposure to air pollution on cognitive performance in healthy, non-smoking, not occupationally exposed adults, considering confounding factors, and using MMSE and Ruff 2 and 7 tests, and it is the first study to investigate the effect of short-term exposure to $PM_{2.5}$ on cognitive performance in healthy adults.

The results from this thesis are related to the research project "Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures" funded by the Health Effects Institute (HEI). This thesis investigated:

1- The degree of misclassification of using central site monitors and indoors at home monitors as a surrogate of personal exposure,

2- The characterization of the profile of the pollutant mixture associated with activities conducted and microenvironments visited by subjects,

3- Contribution to personal exposure associated with different activities and microenvironments pollutant profile, and

4- Contribution of indoor and outdoor sources on personal exposures (i.e. Effect of cooking with gas-appliances and living near busy roads)

The results from this thesis are also related to the research project “Effects of short-term exposure to particulate matter on cognitive performance” to assess the personal short-term exposure to $PM_{2.5}$ from candle burning, and PM from commuting.

All the research took place in Birmingham in the United Kingdom, the second biggest city in the UK after London.

The results from this thesis provide evidence of the significant misclassification between the three locations (i.e. PE, CS’s, and houses), which means that central sites are not a suitable surrogate to assess human exposure to air pollution. It also provides evidence that the activities associated with high concentrations of BC, $PM_{2.5}$ and UFP are travelling in vehicles and commuting, in addition to cooking for UFP. Moreover, it presents a strong evidence that the highest contributor to personal exposure is resting and sleeping at home, in addition to indoors during activities with light exercise; since people spend the majority of their time at home, houses are the highest contributor to personal exposure. Finally, busy roads affect the background concentrations inside houses located on these roads. The occupants are exposed to higher BC concentrations during time spent in these houses especially while sleeping. People are also exposed to higher concentrations of higher $PM_{2.5}$ and UFP in houses located away from busy roads; these high concentrations can be emitted from candle burning, cooking methods (e.g. frying), the products cooked (e.g. fish), the use of household cleaning agents, ETS etc.

The outcomes of this thesis also provide strong evidence that exposure to short-term air pollutants (i.e. $PM_{2.5,}$ PM) from both candle burning emissions and commuting leads to a decline in cognitive performance in healthy adults in terms of cognitive

functioning; in addition, short-term exposure to pollutants from commuting causes a decline in cognitive performance in terms of selective attention (i.e. automatic detection speed). Since pollutants from commuting have not been measured, people may have been exposed to different pollutants during commuting that are not produced from candle burning emissions, also some confounding factors from commuting may affect the results (e.g. noise pollution).

Limitations in this study include the lack of pollutants measurements during commuting to assess the effect of short-term exposure to air pollution, hence, further investigation is recommended in terms of commuting to include data for different pollutants measurements. Also, it is recommended to use real time cognitive performance tests or CNS tests (e.g. Cognitive Assessment Battery (CAB)) that present direct results, concurrently with real time monitors to assess personal exposure before, during and after exposure to different concentration of pollutants, to investigate the correlation between the increase of air pollution and CNS (e.g. cognitive performance), whether on short-term or long-term exposure to air pollutants.

CHAPTER 8: FUTURE DIRECTIONS

The results from this thesis encourages and emphasizes the importance of using monitors at houses to assess personal exposure to air pollution instead of the central sites monitors, given that

- people spend the majority of their time at home,
- they are exposed to pollutants during activities (e.g. cooking, candle burning) or in microenvironments (e.g. kitchen) that cannot be detected in CS monitors,
- long term exposure to low pollutants concentrations and peak concentrations has an adverse effect on human health.

The use of portable sensors is also recommended if possible in other microenvironments to assess human exposure to air pollution such as in vehicles, especially for patients suffering from cardiopulmonary problems and CNS problems. A further recommendation is to use other monitors concurrently with air pollution monitors such as noise pollution monitors to consider the confounding factors, whether in epidemiological studies or in health sectors, in addition to consider other confounding factors such as fatigue, caffeine consumption by using a confounding questionnaire, which can be presented in an application on smart phones to make it easy and accessible all the time, and to limit the use and losing of paper forms. Developing real-time monitors especially made for interior use in houses to detect most or all pollutants in different house locations during different activities, will add more specific important information about the contributors that affect personal

exposure the most. More investigation is needed to assess the long term personal exposure to low pollutants concentrations.

As for the effect of exposure to air pollution on cognitive performance, it is recommended that further studies include more cognitive tests, which means that people who work in psychological sectors need to get the license. It is also important to have more cooperation between the environment, epidemiology and psychology sectors, to increase the findings and knowledge regarding to this issue.

Further study is needed to assess the effect of living in and close to traffic, considering confounding factors such as the pollutants concentrations emitted from personal activities inside home (e.g. lighting candles, using aerosols), and to measure the concentrations of the pollutants at personal exposure not only inside homes, but also outside the house at different locations from the roadside to the pathways by which pollutants enter the house.

It is also worthwhile considering using low-cost sensors to monitor air pollution, to include more subjects, meaning that more data can be collected. Since these low-cost sensors are more affordable, many sensors can be purchased instead of a few expensive ones, and they also consume less power. However, the trade-off is that these sensors may be less accurate and be of poor quality (Jiao et al., 2016), which will result in underestimating or overestimating health effects, thus having a potentially negative effect on decision making. They also may not work for a long time and require frequent batteries changes. Also, their maintenance, calibration, and battery replacement may cost more than their actual prices, and so they may ultimately exceed the cost of a more expensive sensor (Kumar et al., 2015).

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List of Research papers and Presentations

Peer-reviewed article

SHEHAB., M., POPE., F.D. Effects of short-term exposure to particulate matter on cognitive performance. (in review)

SHEHAB., M., SABORIT., J. M. D. & LAM, H. n.d. Correlation between short and long-term exposure to air pollution and cognitive performance in adults and elderly: A systematic review. (in preparation)

Conference presentation

SHEHAB., M., POPE., F.D., n.d. Effects of short-term exposure to particulate matter on cognitive performance. (2017). In: European Aerosol Conference (EAC), Zurich, Switzerland 27 August – 1 September *2017* **(Poster Presentation)**

Appendices

Appendix 1

Outcomes and characteristics of effects of air pollutants on cognitive performance

A1. Table 1: Summary of characteristics of long-term studies (Shehab. et al., n.d.)

Study Reference #, name of study	Location	Sample size	Age	Ethnicity	Study design	Exposure concentration	Exposure assessment methodology
(Sanchez-Rodriguez et al., 2006)	Mexico City and Actopan, Mexico	189 (104 urban, 85 rural)	Urban: 66.8±6.4 Rural: 70.8 ± 8.4	Did not specify	Case-control design	**Mexico City O_3**: 155 ±46 ppb **Mexico City PM_{10}:** 122 ±27 µg/m^3 **Actopan O_3**: 70 ±10 ppb **Actopan PM_{10}:** 104 ±24 µg/m^3	***Geostatistical modelling:*** Assign the average concentrations in Mexico City to urban subjects and the average concentrations in the rural area of Actopan to the rural participants.
(Sun and Gu, 2008) Chinese Longitudinal Health Longevity Survey	Nationwide China 735 districts in 171 cities (urban only)	7358	86.3 ±11.4	Chinese	Cross-sectional analysis Interviewed during April-October 2002	**Air Pollution Index:** 3.5±1.19	***Geostatistical modelling:*** Assign the Air Pollution Index at the city level, which is shared by several districts within the same city
(Chen and Schwartz, 2009) NHANES-III	Nationwide, USA	1764 (879 men, 885 women)	Mean: 37.4 ± 10.9	Non-Hispanic white, non-Hispanic black, Mexican-American	Prospective cohort Cross-sectional analysis (1989-1991)	**1-year O_3:** 26.5 ± 5.2 ppb **1-year PM_{10}:** 37.2 ± 12.8 µg/m^3	***Geostatistical modelling:*** Annual PM_{10} concentration was spatially interpolated using all monitors in the county of residence of the participant and adjoining counties using the inverse-distance-squared from the participant residence to the monitors. Annual O_3 concentration was averaged at the county of residence level.
(Ailshire and Crimmins, 2014)	Nationwide, USA	13,996 (56.08 female)	>50	White (81.09%) African Americans	Prospective cohort	**Annual $PM_{2.5}$ first quartile:** 8.9 ± 0.8 µg/m^3 (for year 2004)	***Geostatistical modelling:*** Annual average $PM_{2.5}$ concentrations were spatially interpolated from available

Health and Retirement Study			64.0 ± 10.4	(9.49%), Hispanics (6.57), Others (2.86%)	Cross-sectional analysis of the 2004 survey	**Annual $PM_{2.5}$ fourth quartile:** 15.4 ± 1.6 μg/m^3 (for year 2004)	reference monitors within 60 km radius to the participant residence using inverse-distance weighing.
(Ranft et al., 2009) SALIA	Ruhr district, Germany	399 women	Range: 68-79 Mean: 74.1 ± 2.6	Did not specify	Prospective cohort (Baseline recruitment 1985-1994; resurvey 2007-2008)	**Average 5-year concentration prior to cognition tests (1980–1993): PM_{10}** Ruhr district area (min, mean, max): 4.4, 48.6, 53.6 μg/m^3 **PM_{10} rural area:** 39.3, 45.0, 49.0 μg/m^3 **Average 5-year concentration after cognition tests (2002–2006): PM_{10}** Ruhr district area: 25.8, 28.3,30.5 μg/m^3 **PM_{10}** rural area: 25.0, 25.0,25.0 μg/m^3	***Nearest monitoring site:*** Assign the concentrations of the nearest monitoring site to the participant residence within an 8 km grid. Total suspended particulate matter (TSP) was converted to PM_{10} using a factor of 0.71. ***Proximity model:*** Exposure was assigned as the distance from the participant residence to the nearest busy road (>10,000 cars/day).
(Zeng et al., 2010) Chinese Longitudinal Health Longevity Survey	China 866 counties and cities	15973 42.7% males 57.3% females	Mean: 86.3	Chinese	Prospective cohort Cross-sectional analysis of responses obtained between 2002 and 2005	**Air Pollution Index measured in 1995**	***Geostatistical modelling:*** Assign the Air Pollution Index at the city level, which is shared by several districts within the same city
(Power et al., 2011) Normative Aging Study	Boston, USA	680 men	Range: 51-97 Mean: 71 ± 7	White	Prospective cohort Cross-sectional analysis of cognitive testing responses obtained	**BC:** 1-year average BC exposure estimates ranged from 0.03 to 1.77 μg/m^3 (mean ± SD, 0.58 ± 0.28 μg/m^3)	***Land-use regression (LUR):*** Long-term exposure computed as the average 365 daily estimate at participant residence prior to date of first cognitive assessment test.

					between 1996 and 2007.		
(Wellenius et al., 2012) MOBILIZE Boston Study	Boston, USA	765 (276 men, 489 women)	≥65 Mean: 78.1 ± 5.4	White, other	Prospective cohort Longitudinal study (Baseline recruitment 2005-2008; median follow-up of 16.8 months)	**Annual black carbon (BC):** 0.15 - 0.98 μg/m^3 (median: 0.36 μg/m^3)	***Proximity model:*** Long-term exposure: Residential distance to major roadways ***Land-use regression (LUR):*** Long-term exposure computed as the average 365 daily estimate at participant residence prior to date of first cognitive assessment test
(Weuve et al., 2012) Nurses' Health Study Cognitive Cohort	USA	19,409 women	≥70	Did not specify	Prospective cohort Longitudinal study (Sub-cohort of NHS: 1995-2001; participants resurveyed in 1997-2004; 2002-2008)	**$PM_{2.5}$:** 2.1-33.7 μg/m^3 **$PM_{2.5-10}$:** 0.1 - 69 μg/m^3	***Land-use regression (LUR):*** Long-term exposure computed as the average preceding month, year, 2 years and 5 years, and from 1988 to preceding month for each participant residence prior to date of cognitive assessment test.
(Loop et al., 2013) REGARDS study	USA 38 contiguous states	20,150 55% female 45% male	Lowest $PM_{2.5}$ quartile: 64.8 ± 9.2 Highest $PM_{2.5}$ quarile: 64.0 ± 9.2	59% white 41% other ethnicities	Prospective cohort Longitudinal study Recruited 2003-2007 Followed up 4-5 years after baseline test	**Lowest $PM_{2.5}$ quartile:** 6.6-12.2 μg/m^3 **Highest $PM_{2.5}$ quartile:** 14.8-21.0 μg/m^3	***Hybrid modelling:*** Combination of $PM_{2.5}$ estimated from MODIS AOD and $PM_{2.5}$ measured at the EPA Air Quality System using the Al-Hamdan et al (2009) algorithm to create $PM_{2.5}$ concentrtaions on a 10km grid.

(Gatto et al., 2014) BVAIR, WISH, ELITE	Los Angeles, USA	1496 (308 men, 1188 women)	Mean: 60.5 ± 8.1	Caucasian, African-American, Hispanic, Asian/Pacific Island/Native American	Cross-sectional analysis of 3 randomised controlled trials (enrolment period 2000-2006)	**Men: NO_2:** 29.1 ± 7.1 ppb; **$PM_{2.5}$:** 20.2 ± 3.5 µg/m^3 **; O_3:** 37.7 ± 5.7 ppb **Women: NO_2:** 24.3 ± 6.3 ppb; **$PM_{2.5}$:** 16.5 ± 3.3 µg/m^3**; O_3:** 40.5 ± 5.2 ppb	***Geostatistical modelling:*** Annual average concentrations were spatially interpolated from nearest monitoring site to participant residence using inverse-distance-squared weighing. They used local stations within 5 k of residence, or calculation for 3 stations within 100 km of residence.
(Tonne et al., 2014) Whitehall II	Greater London, UK	2,867 (65% men)	Mean: 66 ± 6	White	Prospective cohort Longitudinal analysis (Baseline assessment 2002-2004; resurveyed in 2007-2009)	**PM_{10} (µg/m^3)** Average (SD) Total 5-year average mean 23.4 (1.5)**;** Exhaust PM_{10} 5-year average mean 0.72 (0.27) **$PM_{2.5}$ (µg/m^3):** Total 5-year average mean 14.9(0.9); Exhaust $PM_{2.5}$ 5-year average mean 0.64 (0.25)	***Dispersion modelling:*** KCLurban dispersion model was used to compute annual average concentrations of PM_{10}, PM_{10} from traffic only, $PM_{2.5}$ and $PM_{2.5}$ from traffic only at resolution 20m x 20m. Annual average was calculated within 25 m of the residence for 1 year average (lags 0, 1, 2, 3,4), 3 year average and 5 year average prior to cognition assessment test.
(Tallon et al., 2017)	USA	from 2005-2006: 1551 women, 1454 men from 2010-2011: 1839 women,	from 2005-2006: 69.30 (7.85) from 2010-2011: 72.38 (8.10)	Non-Hispanic white Non-Hispanic black Hispanic non-black Other ethnicities	Cross-sectional	**$PM_{2.5}$** (µg/m3): 2005-2006: 13.07 (2.81), 2010-2011: 10.23 (2.50) **NO_2** (ppb): 2005-2006: 14.92 (7.23) 2010-2011: 10.13 (6.28)	***GIS-based spatio-temporal models:*** To estimate fine particles ($PM_{2.5}$) ***nearest EPA monitors:*** To estimate nitrogen dioxide (NO_2)

		1538 men					
(Zijlema et al., 2017)	Barcelona, Spain; Doetinchem, the Netherlands; Stoke-on-Trent, United Kingdom	1628 women	48.1 (15.2)	Not specified	Cross-sectional	**Natural outdoor environments (NOE):** NOE total visits last 4 weeks: 11 (21) NOE total time spent visiting (hours spent last 4 weeks): 14.0 (31.5)	**geographical information systems (GIS)** **face-to-face questionnaires**
(Reed et al., 2014)	Rotorua, New Zealand	1,637 (656 men, 981 women)	Range: 18-65	European, Maori, and other (Asians and Pacific Island people)	Cross-sectional	**H_2S:** 0–64 ppb (0–88 µg/m3)	***Microenvironment time-weighted average Exposure*:** H_2S exposures at homes, schools and workplaces were estimated using city-wide networks of passive H_2S samplers and kriging to create exposure surfaces. Exposure concentration was calculated as the time-weighted exposures at school, home and workplace. ***Microenvironment Exposure*:** The maximum average exposure selected at school, home or work microenvironment calculated using the estimated kriging exposure surface concentrations derived from the H_2S passive sampler network.
(Ailshire and Clarke, 2015) Americans' Changing Lives survey	Nationwide, USA	780 (61% women)	≥55	non-Hispanic black and white	Prospective cohort Cross-sectional analysis of the 2001/2002 survey	**Annual $PM_{2.5}$:** 13.8 ± 3.1 µg/m^3 (for year 2000)	***Geostatistical modelling:*** Annual average $PM_{2.5}$ concentrations were spatially interpolated from available reference monitors within 60 km radius to the participant residence using inverse-distance weighing.

(Schikowski et al., 2015) SALIA cohort	North Rhine-Westfalia, Germany	789 women	73.4 ±3.05	Not specified	Prospective cohort Cross-sectional analysis of 2007-2009 survey	**PM10:** 26.4 (2.2) µg/m^3 Median (IQR) **$PM_{2.5}$:** 17.4 (1.9) µg/m^3 **$PM_{2.5}$ abs:** 1.3 (0.4) 1/m **NO_x :** 39.5 (23.4) µg/m^3 **NO_2:** 25.9 (9.6) µg/m^3	***Land-use regression (LUR):*** Concentrations at the participant's home were estimated using the ESCAPE LUR model (Beelen et al., 2013). ***Proximity model:*** Daily traffic load within 100-m buffer around the home was calculated by summing of the products of the number of vehicles from all roads with >5000 cars/day times the street section lengh in the 100-m buffer.

APPENDIX 2

Materials for use of novel sensors to assess human exposure to airborne pollutants

Interaction with researchers during the sampling

To deploy and collect your air personal sampler, it will be necessary for a member of our team to meet with you during the first and last sampling day at your home. We will also do a courtesy visit during your sampling period to check the status of the sensors.

It is not however our intention to intrude on your private life and if any of this sampling were to be inconvenient you would only need to inform us and we would discontinue it.

The researchers would help you to fill the questionnaires.

Anonymous and confidential results

- Each participant will be assigned a random ID code.
- The results of the measurements will be anonymised
- Those who carry out the data analysis will not know which participant gave which samples.
- This will be known only to the Principal Investigator.
- The information linking the participant identities and ID codes will be kept in a secure locked cabinet.

Contact information

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UNIVERSITY OF BIRMINGHAM

HEI HEALTH EFFECTS INSTITUTE

Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures to air pollution

VOLUNTEERS NEDEED

WE NEED A HAND

WOULD YOU LIKE TO KNOW WHAT ARE YOU BREATHING IN?

GET £60 BY PARTICIPATING

How you can contribute…

We are recruiting 40 healthy, non-smoking **volunteers** from the general public to take part in our study.

We aim to measure the air that you are breathing during your normal routine activities. Our purpose is to understand the sources of air pollution that are affecting the air that people from the general population are breathing in. In particular, we are interested to know how traffic and cooking fumes affect the air that we are breathing in.

Volunteers who complete the study will each be paid £60 as compensation for any inconvenience which the study may cause them.

The results of the volunteer's sample analysis would be made available to the volunteer if requested.

Research aims

- To identify the **sources** of air pollution that mostly affect personal exposure.

- To assess the association between air pollution and the **effect of** distance of homes to **traffic and the use of gas for cooking.**

Research information

Our study is not directly concerned with evaluating your health. It is however concerned with measuring the quantity of air contaminants that are breathing in during our daily routines.

Our study focus on a group of pollutants that have been traditionally associated with traffic emissions, but which can be released from other sources found typically at home like cooking.

The particular set of pollutants that we want to study are ultrafine particulate matter (UFP), which are very tiny particles; fine particulate matter ($PM_{2.5}$); and black carbon (BC), which is a pollutant generally associated soot from diesel emissions.

How your participating helps us

Gathering exposure information at the personal level will advance our knowledge of the true inhalation of air pollution.

In addition, since the sensors can collect information continuously, we will be able to identify which activities and locations contribute the most to the total exposure to air pollution.

Your involvement - Air Pollution Sensors

We will ask you to carry a backpack that contains 3 small air pollution sensors with you at all times for a period of 4 consecutive days.

Another set of the same 3 air pollution sensors will be enclosed in a briefcase and placed at your home for the same period.

You can see pictures of the 3 sensors and the backpack below.

UFP: Discmini

BC: MicroAethalometer

$PM_{2.5}$: MicroPEM

Backpack

The **sampling** will be **scheduled at a convenient period for you.**

We would like you to follow your normal activities, there is not need to change your usual routine.

Your involvement - Questionnaires

Volunteers will need to list in an activity diary their activities, where have been and what they where doing (which will take about 20 minutes).

We will also ask to complete a questionnaire about characteristics of your home (which will take about 10 minutes) to have an idea of possible sources of air pollution inside and outside the house.

The researcher will help you to fill the forms if requested. We will provide you with a voice recorder that will help you mark your activities.

With this information it will be possible to reconstruct exposures and to understand factors (such as length of time in traffic) as well as lifestyle factors that can influence you exposure to these chemicals.

UNIVERSITY OF BIRMINGHAM

DIVISION OF ENVIRONMENTAL HEALTH & RISK MANAGEMENT

HEADLINE:
VOLUNTEERS FOR AIR POLLUTION RESEARCH PROJECT

ANNOUNCEMENT:

Do you live near polluted area?

Do you think that you are surrounded with polluted air?

We are seeking to recruit volunteers to take part in a research project investigating the human personal exposures to airborne pollutants.

If you are interested, please contact Ms Maryam Shehab [redacted] or phone number [redacted]. A reward of £60 will be given for the participants to thank you for volunteering.

UNIVERSITY OF BIRMINGHAM

School of Geography, Earth and Environmental Sciences

PARTICIPANTS NEEDED FOR AIR POLLUTION RESEARCH PROJECT

Do you....

- Live near polluted area?
- Think that you are surrounded with polluted air?

Are you....

- Non-smoker?
- Healthy adult?

We are seeking to recruit volunteers to take part in a research project investigating the human personal exposures to airborne pollutants

A reward of £60 will be given for the participants to thank you for volunteering

If you are interested, please contact Ms Maryam Shehab [redacted] or phone number [redacted]

[redacted]

Online announcement: were posted in mybham portal website

ANNOUNCEMENT: Are you non-smoker, Healthy adult and first language English? We are seeking to recruit volunteers to take part in a research project investigating the human personal exposures to airborne pollutants. A reward of £60 will be given for the participants to thank you for volunteering. If you are interested, please contact Ms Maryam Shehab [redacted]

PARTICIPANT INFORMATION SHEET

HEI Project – Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures

The purpose of this information sheet is to provide background to our research project and to explain what will be asked of you if you agree to enrol as a participant.

Funding

Our project is funded by the Health Effects Institute. The Health Effects Institute is a non-profit corporation chartered in 1980 as an independent research organization to provide high-quality, impartial, and relevant science on the health effects of air pollution.

Background

The particular focus of our study is on a group of pollutants that have been traditionally associated with traffic emissions, but which can be released from other sources found typically found at home like cooking. The particular set of pollutants that we want to study are ultra fine

particulate matter (UFP), which are particles with a diameter smaller than 0.1 µm; fine particulate matter ($PM_{2.5}$), which are particles with a diameter smaller than 2.5 µm; black carbon, which is a pollutant generally associated with diesel emissions; and NO_2, which is a gas generated during combustion processes.

Most of the national and international guidelines limiting our exposure to these air pollutants have been established from epidemiological studies, which are medical studies which in this case link pollution levels with a medical outcome (e.g. respiratory illness). Epidemiological studies generally use the concentrations of these pollutants measured at a centrally located monitoring site to establish the effect of these pollutants on human health. However, recent technological advances have made available small and light sensors which can be carried by people and record their personal level of exposure to pollution.

Gathering exposure information at the personal level will advance our knowledge of the true exposure to air pollution and we will be able to better understand the true magnitude of the effect of air pollution on human health. In addition, since the sensors can collect information continuously, we will be able to identify which activities and locations contribute the most to the total exposure to air pollution.

Your involvement

Our study is <u>not</u> directly concerned with evaluating your health. It is however concerned with measuring your exposure to several air pollutants. In order to do this, we are recruiting 40 non-smoking volunteers from the general public. Those who complete the study will each be paid £120 as compensation for any inconvenience which the study may cause them.

In return, our researchers will ask you to carry a personal air sampler with you at all times for a period of 4 consecutive days during the winter months and to repeat the measurements for another 4 consecutive days during the summer months. Both sampling periods will be scheduled at a convenient period for you.

The sampler will be enclosed in a backpack or small briefcase at your convenience. The briefcase has dimensions approximately 40 cm (width) x 35 cm (breadth) x 12 cm (depth). The sensors weight about 3.5-4 kg.

If you find the noise of the pumps from the personal air sampler disturb you at night (they will not during the day as they are designed to be very quiet), then the sampler can be placed in another room of the house while you are in bed.

From the samples collected, we will know how much air pollution you have been exposed to over the sampling period and therefore how much you are likely to have breathed. To deploy and collect your air personal sampler, it will be necessary for a member of our team to meet with you on the sampling day at a mutually agreeable location, probably your home.

In addition, we will also ask you to carry a small accelerometer, which weights 9 grams, to record the intensity of your physical activities during the day. This information will let us know how fast and how much pollutant you have been breathing during specific activities.

In order to understand the sources of air pollution to your personal exposure we will also collect samples of air from within your home. For this, we will place an additional similar sampler in your home.

It is not however our intention to intrude on your private life and if any of this sampling were to be inconvenient you would only need to inform us and we would discontinue it.

We would like you to follow your normal activities; there is no need to change your usual routine.

In order to understand factors such as where you live and work as well as lifestyle factors influencing your exposure to air pollution we will ask you to fill some questionnaires. In these, you will detail possible sources of pollutants inside and outside your home, a lifestyle questionnaire that detail daily activities that might affect the air you breathe. It will take about 15 minutes to complete all the questionnaires, and you would have help from the researcher to fill them if requested. We will provide you with a voice recorder that will help you log the activities during the day, so it is easy to fill the questionnaire.

GPS track records

In order to facilitate the recording of your trips and journeys along the day, we will provide you with a GPS track logger. This is a device that records your geographical position on a map during the time that you wear the GPS device. It works in a similar way to a Satnav on a car in identifying your position, and records details of your journey.

Anonymous and confidential results

Each participant will be assigned a random ID code. The results of the measurements will be anonymised and those who carry out the data analysis will not know which participant gave which samples. This will be known only to me, the Principal Investigator. The information linking the participant identities and ID codes will be kept in a secure locked cabinet.

The GPS tracks (i.e. record of your geographical position during the sampling day) will be saved with the same ID code that it is given to each subject and the information will be treated as

confidential. No GPS data within 100 m of the subject's home, subject's office or any other location in a residential area that the subject might visit (e.g. friend/family house) will be displayed in any publication or public site.

Further questions / actions

If after reading this participant information sheet you have any questions, please contact me using the following details. If after this you are entirely happy in participating in the study, please sign the attached consent form and return it to a member of our research team in the enclosed pre-paid envelope.

Contact details: Name: Maryam Shehab

E-mail: [redacted]

Telephone: [redacted]

Withdrawing from the project

If after giving your consent to participate in this project, you want to withdraw, you can do so at any time up to 2 months after your sampling has been completed. For doing so, you just need to contact myself at [redacted] and express your wish to withdrawn from the study. We will then remove all your details from our database according to your wish.

Dr. Juana Maria Delgado-Saborit

Research Fellow and HEI project Principal Investigator

THE UNIVERSITY
OF BIRMINGHAM

HEI Project – Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures

SCREENING QUESTIONNAIRE

The HEI Project is open to people who are over 18 years of age above and who regard themselves as being in good health.

We are aiming to recruit non-smoking adult subjects to conduct the exposure measurement of airborne particles in personal exposures and in the main indoor environments relevant to personal exposures, the home. Subjects will be recruited in urban and suburban areas. We want to recruit people in four groups depending on the distance of their house to a main road and the type of appliance used for cooking (i.e. gas or electrical hobs). The information collected in this questionnaire would help us group you into the relevant group.

Please complete the questionnaire in capital letters.

Your Details:

1. Full Name

_____

2. Are you:

☐ Male

☐ Female

3. What is your age?

☐ 18 - 25

26 - 35

☐ 36 - 45

46 - 55

☐ 56 - 65

66 and over

4. Ethnicity

White: British ☐ Irish ☐ Other ☐ _____

Asian: Indian ☐ Pakistani ☐ Bangladeshi ☐ Others ☐_____

Black: Caribbean ☐ African ☐ Other ☐_____

Other:_____

5. What is your home address?

_____
_____
_____

6. How would you like us to contact you? Please provide relevant details
   - ☐ Mobile phone: _____
   - ☐ Home phone: _____
   - ☐ Work phone: _____
   - ☐ Email: _____

Your house

7. Do you live in a house or a flat?
   - ☐ Yes
   - ☐ No

8. If you live in a flat, what floor is it located?
   - ☐ Ground floor
   - ☐ First floor
   - ☐ Second floor and above

9. How busy is the street where your house is located?
   - ☐ Quiet, only residential traffic
   - ☐ Busy sometimes
   - ☐ Busy most times
   - ☐ Busy all the time

10. What kind appliance do you use for cooking?
   - ☐ Gas
   - ☐ Electricity
   - ☐ Other, (Please specify:_____)

11. Do you use a fume exhaust when coking?
   - ☐ Yes
   - ☐ No

Your Occupation:

12. What is your occupation?

_____

13. Please describe your occupation.
I work in open air
I work in an office
I work indoors, but not in an office
Are printers, photocopiers or fax in the office

14. Is your occupation:

☐ Full Time
☐ Part Time
☐ Job Share
☐ Shift Work

Other, please describe_____

15. Please indicate what hours you work, e.g. 9am – 5pm e.t.c.

_____

16. What floor is your office located.

☐ Ground floor
☐ First floor
☐ Second floor and above

17. How busy is the street where your office is located?

☐ Quiet, only residential traffic
☐ Busy sometimes
☐ Busy most times
☐ Busy all the time

Your Travel:

18. How many miles is your home from your workplace?

☐ Less than 5 miles
☐ 5 – 15 miles
☐ 15 – 30 miles

More than 30 miles

19. How do you travel to work?

☐ Car
☐ Train
☐ Bus
☐ Cycle
☐ Walk

Other, please describe _____

20. How long does your journey to work take you on average?

☐ Less than 5 minutes traveling time
☐ 5 - 15 minutes traveling time
☐ 15 – 30 minutes travelling time
☐ More than 30 minutes travelling time please specify:_____

21. What time do you usually leave your home in the morning to get to work?

_____

22. Do you use a vehicle for your job?

☐ Yes
No

23. If yes, how long per day on average would you say you spend in your vehicle for work purposes (excluding travel to and from work)?
☐ Less than 30 minutes
☐ 30 – 60 minutes
☐ 1 – 3 hours
☐ More than 3 hours

Other Information:

24. Your weekly level of exercise is:
☐ Gym sessions at least 2 days a week
Please, specify activity:_____
☐ 30 min moderate-intensity physical activity (e.g. walking) or exercise, 5 days a week
☐ 20-30 min moderate-intensity physical activity, 3 days a week
☐ I do not exercise regularly
☐ Other, please specify:_____

25. Do you smoke?
☐ Yes
No

26. Does anyone else in your house smoke?
☐ Yes
No

27. Do you come into contact with tobacco smoke at work?
☐ Yes
No

28. How many people including yourself live in your home?
☐ 1
2-3
4+

43. Finally, please tell us why you decided to respond to our advertisement

Thank-you for completing our screening questionnaire. Please now return it to us along with your consent form in the freepost envelope provided. If you have any queries regarding this questionnaire please contact Ms Maryam Shehab on 0121 414 5557

HEI PROJECT:

Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures

PARTICIPANTS BASELINE QUESTIONNAIRE

Volunteers ID: Date:

PART A: GENERAL INFORMATION ABOUT YOUR INDOOR ENVIRONMENT

A.1 (a) DESCRIBE THE LOCATION OF THE HOME. Please tick one box

Rural area ☐

Suburb	☐
City centre	☐

A.1 (b) DESCRIBE THE LOCATION OF THE OFFICE. Please tick one box

Rural area	☐
Suburb	☐
City centre	☐

A.2 DESCRIBE THE TYPE OF DWELLING. Please tick one box that describes best Home and Office

	Home	Office
Flat	☐	☐
Centre terrace house	☐	☐
End terrace house	☐	☐
Semi-detached house	☐	☐
Detached house	☐	☐

IF YOU DO NOT LIVE IN A FLAT, PLEASE GO TO QUESTION A.6

A.3 (a) ON WHICH FLOOR IS YOUR HOME/ FLAT LOCATED?

(Please specify, e.g. 1, 2, 3 or Basement =B, Ground Floor = F) ☐

A.3 (b) ON WHICH FLOOR IS YOUR OFFICE LOCATED?

(Please specify, e.g. 1, 2, 3 or Basement =B, Ground Floor = F) ☐

A.4 (a) WHAT IS IMMEDIATELY BELOW YOUR HOME/ FLAT?

Please tick one box

- The ground ☐
- Another flat ☐
- Garage ☐
- Other (please describe below) ☐

A.4 (b) WHAT IS IMMEDIATELY BELOW YOUR OFFICE?

Please tick one box

- The ground ☐
- Another flat ☐

Garage ☐

Other (please describe below) ☐

A.5 (a) WHAT IS IMMEDIATELY ABOVE YOUR HOME/ FLAT?

Please tick one box

The roof – is it a top floor flat ☐

Another flat ☐

Other (please describe below) ☐

A.5 (b) WHAT IS IMMEDIATELY ABOVE YOUR OFFICE?

Please tick one box

The roof – is it a top floor flat ☐

Another flat ☐

Other (please describe below) ☐

A.6 DO YOU HAVE A GARAGE?

	Yes	No
Home	☐	☐
Office	☐	☐

If no, please go to Part B.

A.7 IS THE GARAGE PART OF YOUR HOME AND OR OFFICE (OR DIRECTLY ATTACHED TO

THE UNDERNEATH OR SIDE OF YOUR HOME AND OR OFFICE)?

	Yes	No
Home	☐	☐
Office	☐	☐

If no, please go to Part B.

A.8 (a) DO YOU KEEP A CAR(S) IN THE GARAGE?

	Home	Office
Usually	☐	☐
Sometimes	☐	☐

☐ ☐

Never

If never, please go to Part B.

(b) HOW MANY CARS ARE NORMALLY PARKED IN YOUR OFFICE GARAGE?

Home

Office

(C) WHAT TYPE OF FUEL DOES THE DIFFERENT CARS PARKED IN THE GARAGE RUN ON?

	Home	Office
Petrol	☐	☐
Unleaded petrol	☐	☐
Diesel	☐	☐
All of the above	☐	☐
Don't know	☐	☐

A.9 WHICH ROOM HAS A DOOR TO THE GARAGE? Please tick one box describing what applies best

to your Home and Office

	Home	Office
Hall	☐	☐
Kitchen	☐	☐
Utility room	☐	☐
Living room	☐	☐
None	☐	☐
Others (Please describe below)	☐	☐

PART B: HEATING & COOKING

B.1 HOW MANY ROOMS DO YOU USUALLY HEAT AT THIS TIME OF YEAR?

Write a number in each box

Living rooms *(include studies, dining rooms etc. but not kitchen diners or living rooms with kitchen included)* ☐

Living room or dining room which includes kitchen ☐

Kitchen ☐

Bedrooms ☐

Bathrooms ☐

Office ☐

Other rooms ☐

B.2 WHAT DO YOU USE AS THE MAIN METHOD OF HEATING AT THIS TIME OF YEAR?

WHAT FUEL DO YOU USE FOR YOUR MAIN HEATING?
Please tick one box describing what applies best to your Home and Office

	Home	Office
Natural gas	☐	☐

Electricity	☐	☐
Bottled gas	☐	☐
Others(Please describe below)	☐	☐

(b) WHAT TYPE OF HEATING SYSTEM DO YOU USE FOR YOUR MAIN HEATING?
Please tick one box describing what applies best to your Home and Office

	Home	Office
Electric storage heater	☐	☐
Central heating with radiators	☐	☐
Warm air central heating	☐	☐
Individual heaters or fires in each heated room	☐	☐
Others(Please describe below)	☐	☐

B.3 WHERE IS YOUR BOILER LOCATED?

Please tick one box describing what applies best to your Home and Office

	Home	Office
Kitchen	☐	☐
Hallway	☐	☐
Under stairs	☐	☐

Others(Please describe below)	☐	☐

B.4 HAVE YOU USED ANY ADDITIONAL TYPE OF HEATING DURING THE SAMPLING WEEK?

Please tick one box describing what applies best to your Home and Office

	Home	Office
Yes	☐	☐
No	☐	☐

If no, please go to B.6

B.5 WHAT TYPE OF ADDITIONAL HEATING DO YOU USE MOST?

(a) WHAT FUEL DOES IT USE?

Please tick one box describing what applies best to your Home and Office

	Home	Office
Natural gas	☐	☐
Electricity	☐	☐
Bottled gas	☐	☐
Coal /coke	☐	☐
Wood	☐	☐
Paraffin	☐	☐
Other (Please describe below)	☐	☐

(b) WHAT TYPE OF HEATING SYSTEM DID YOU USE FOR YOUR ADDITIONAL HEATING. Please tick one box describing what applies best to your Home and Office

	Home	Office
Electric storage heaters	☐	☐
Central heating with radiators	☐	☐
Warm air central heating	☐	☐
Individual heaters or fires in each heated room	☐	☐
Other (Please describe below)	☐	☐

B.6 DO YOU USE ANY FURTHER GAS OR SOLID FUEL WHICH YOU HAVE NOT INCLUDED IN YOUR MAIN OR ADDITIONAL HEATING (NOT INCLUDING COOKING FUEL)?

Please tick one box describing what applies best to your Home and Office

	Home	Office
Yes (please describe below)	☐	☐
No	☐	☐

If yes, please describe in box below

B.7 AT WHAT HOURS WAS YOUR HOUSE HEATED?

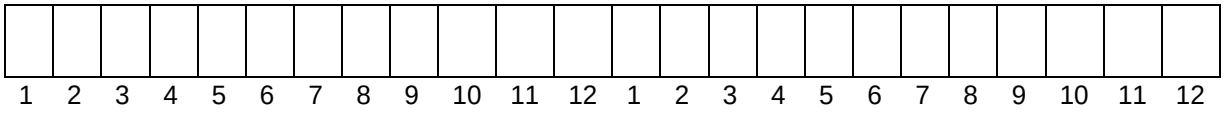
Please mark off the boxes to show when you have heating on

1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12

Midnight Midday

B.8 AT WHAT HOURS WAS YOUR OFFICE HEATED?

Please mark off the boxes to show when you have heating on



B.9 WHAT MAIN COOKING FUEL DO YOU USE?

Please tick one box describing what applies best to your Home and Office

	Home	Office
Natural gas	☐	☐
Electricity	☐	☐
Bottled gas	☐	☐
Others(Please describe below)	☐	☐

IF YOU DO NOT USE GAS FOR COOKING PLEASE GO TO PART B.11

B.10 HOW MANY HOURS WAS YOUR GAS COOKER USED IN THE SAMPLING WEEK?

Home Office

Hours ☐☐

B.11 DO YOU EVER USE THE GAS COOKER, WHEN YOU ARE NOT COOKING, TO HEAT THE KITCHEN (OR ANY OTHER PART OF THE HOME)?

Please tick one box describing what applies best to your Home and Office

	Home	Office
Yes, regularly	☐	☐
Yes, sometimes	☐	☐
Yes, only occasionally	☐	☐
No, never	☐	☐

B.12 DO YOU HAVE A COOKER HOOD?

Include cooker hoods which extract air to the outside, but NOT hoods which only filter air and return it to the kitchen. *Please tick one box that describes best Home and Office*

	Home	Office
Yes	☐	☐
No	☐	☐

If no, please go to PART C

B.13 HOW OFTEN IS THE COOKER HOOD USED?

Please tick one box describing what applies best to your Home and Office

	Home	Office
Fan not used	☐	☐
Fan sometimes used	☐	☐
Fan normally used when room in use	☐	☐

PART C: WINDOWS & VENTILATION

C.1 PLEASE INDICATE WHICH DIRECTION THE WINDOWS IN YOUR HOME/ FLAT FACE.

Please tick more than one box if applicable

	Street Side	BackGarden	Side Street/Side Alley	Other (please specify)
Kitchen				
Bathroom				
Living room				
Your bedroom				
Others*				
Office				

*Please specify (e.g. dining room, second bedroom, corridor, etc.)

C.2 HOW OFTEN WAS THE WINDOWS OPENED DURING THE SAMPLING WEEK? Please tick one box for each room type

	All or most of the time	Part of the day	Only when needed	Rarely or never	No window	Don't know
Kitchen						
Bathroom						
Living rooms						
Bedrooms						
Other rooms						
Office						

C.3 DID YOU LEAVE WINDOWS OPEN AT NIGHT DURING THE SAMPLING WEEK?

Please tick one box for each room type

	Yes, all or most nights	Sometimes	Rarely or never	Don't know
Kitchen				
Bathroom				

Living rooms				
Bedrooms				
Other rooms				
Office				

C.4 DO YOU HAVE DOUBLE GLAZING? Please tick one box describing what applies best to your

Home and Office.

	Home	Office
Yes	☐	☐
No	☐	☐

C.5 DO YOU HAVE ANY ELECTRIC EXTRACTOR FANS?

This is a question about electric fans which extract air from the home and or office to the outside. These fans are fitted in a window or wall, you may have one in a ceiling which blows air up a pipe and through the roof.

Do not include cooker hoods. Please tick one box describing what applies best to your Home and Office

	Home	Office
Yes	☐	☐
No	☐	☐

If no, please go to PART C.7

C.6 PLEASE INDICATE WHETHER THERE IS A FAN IN THE ROOMS LISTED IN THE TABLE BELOW, AND WHETHER IT IS USED, BY TICKING THE APPROPRIATE BOXES

	No fan	Fan present, but not used	Fan sometimes used	Fan normally used when room in use
Kitchen				
Bathroom				
Other rooms				
Office				

C.7 WOULD YOU SAY THAT WINDOWS AND/OR VENTILATORS IN YOUR HOME AND OR OFFICE PROVIDE ADEQUATE FRESH AIR? Please tick one box describing what applies best to your Home and Office

	Home	Office
Usually	☐	☐
	☐	☐
Sometimes		
Never	☐	☐

PART D: THINGS THAT AFFECT THE AIR IN YOUR HOME AND OFFICE

D.1 DO YOU SMOKE INDOORS AT HOME?

Yes ☐

No ☐

D.2 DOES ANYONE ELSE IN YOUR HOUSEHOLD SMOKE INDOORS AT HOME?

Yes ☐

No ☐

D.3 DOES ANYONE ELSE REGULARLY SMOKE INDOORS AT HOME?

Yes ☐

No ☐

IF NOBODY SMOKES PLEASE GO TO D.5

D.4 FOR EACH PERSON WHO SMOKES INSIDE YOUR HOME PLEASE ESTIMATE THE AMOUNT SMOKED PER WEEK INSIDE YOUR HOME.

PERSON	1	2	3	4	5	6
Cigarettes (number)						
Pipe tobacco (oz)						
Small cigars (number)						
Large cigars (number)						

D.5 HAVE YOU NOTICED ANY PATCHES OF MOULD ON THE WALLS OR CEILINGS OF YOUR HOME AND OR OFFICE AT ANY TIME IN THE LAST 12 MONTHS?

	Home	Office
Yes	☐	☐
No	☐	☐

If yes, please indicate in which room(s) in the box below

D.6 WHICH ROOMS ARE YOUR PET ALLOWED IN?

Kitchen	☐
Living rooms	☐
Bedrooms	☐
Other rooms	☐
No pets	☐

D.7 HAVE YOU USED ANY GEMICIDE, PESTICIDE, OR PARASITE KILLER DURING THE SAMPLING WEEK:

	Home	office
Yes (please describe below)	☐	☐
No	☐	☐

D.8 DID YOU DO ANY DIY?

Yes	☐
No	☐

If yes, please specify any recent DIY in the box below, including approximately when it was done.

D.9 PLEASE TICK TO INDICATE HOW OFTEN YOU DO THE FOLLOWING

	Most days or every day	About once a week	Less often	Rarely / never

Hoover				
Dust				

D.10 PLEASE TICK TO INDICATE HOW OFTEN YOU USE THE FOLLOWING

	Most days or every day	About once a week	Less often	Rarely / never
Aerosol insect killer				
Aerosol air freshener				
Other aerosol				

D.11 IS YOUR HOME OR AND OFFICE FLOOR, WOODEN AND OR CARPETED.

Please tick one box describing what applies best to your Home and Office

	Home	office
Carpet	☐	☐
Wooden	☐	☐
Tiles	☐	☐
Synthetic flooring (i.e. Linoleum)	☐	☐

D.12 DO YOU USE THE FOLLOWING EQUIPMENT; DESCRIBE THE DISTANCE

Office Equipments	Location in the office	Distance from you	How often do you use it daily
Photocopier			
Printer			
Faxes			

Researcher use only

ID Code:

CONSENT FORM

HEI Project – Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures

I have read and understood the Participant Information Sheet provided to me with this Consent Form. Any outstanding questions have been answered satisfactorily by the research team. I agree to participate in the study by carrying the personal air sampler, and by allowing measurements of air pollutant concentrations to be made in my home and filling the corresponding information sheets. I agree to repeat the same set of measurements within 6 months.

I confirm that I have been informed that a GPS data logger will be located in my sampling equipment to log my geographical position on the day that sampling occurs. I have been informed that my GPS data will be treated as confidential information. I have been informed that any GPS data within 100 m of my home, my office or any other residential location that I might visit within my sampling day will not be displayed in any publication or public document. I therefore agree to log my GPS data during the sampling date and I give my consent to use the GPS information for research only purposes

As a minor compensation for any inconvenience caused, I will be receiving a sum of £60 upon completion of one sampling period (4 days) and £120 upon the completion of two sampling periods (8 days).

I have been informed of my right to withdraw at anytime, even if I sign this consent form.

NAME OF VOLUNTEER SUBJECT:

.....

SIGNATURE: .....

DATE: .....

NAME OF RESEARCHER:

.....

SIGNATURE: .....

DATE: .....

NAME OF WITNESS:

.....

SIGNATURE: .....

DATE: .....

Confirmation form

THE UNIVERSITY OF BIRMINGHAM

Dr. Juana Maria Delgado Saborit, Lecturer at the University of Birmingham confirms that (Name) is taking part on a study on personal exposure to airborne pollutants. He/ She is carrying a bag that contains several air sampling sensors for this purpose for the period (Date) to (date). The sensors contained in the bag are:

One RTI microPEM sensor to measure particulate matter with aerodynamic diameter less than 2.5 micrometers
One AethsLabs microaethalometer AE-51 to measure black carbon
One Discmini Testo Matter Aerosol sensor to measure ultrafine particles

Signed:

Dr. Juana Maria Delgado Saborit

If there are any problems or concerns please contact the research office on [redacted].

HEI Project

Use of Real-time sensors to assess misclassification and to identify mai contributing to peak and chronic exposures

UNIVERSITY OF BIRMINGHAM

PARTICIPANT INSTRUCTION SHEET

This sheet is to remind you of the different tasks we ask you to complete during this week while you are carrying the sampling case around with you. If you have any questions about any of the activities or forms we have asked you to complete them please contact Maryam Shehab on [redacted].

Security issues:

For security reasons and to avoid anyone tampering with the air samplers, the monitor cases will be locked. At home, the monitor cases will be located in a place that does not interfere with walkways. You are provided with a letter confirming your status as a volunteer of this project, a contact number for emergencies and a leaflet explaining what is inside the sampling bag, in case you are enquired by the police.

Personal Sampling Case:

Please carry the sampling case around wherever you go during the day you have the case. If you are at work or home there is no need to carry the case with, but it is preferable f you could have the case within arm's reach of you and off floor level e.g. on a table.

GPS logger, heart rate and accelerometer:

You have been provided with a GPS to log your current geolocation and an accelerometer to log your physical activity. The GPS and accelerometer are enclosed in the wait pouch that we have provided you.

We have also provided with a heart rate monitor. Please wear this in your wrist during the time of the sampling.

Home Sampling Cases:

Once the researcher has set up the home or office sampling case there is no need for you to move it. The home sampling case will remain in your home for 4 days and will be collected by the researcher upon completion of your sampling programme. The researcher will make sure the case is located in a place that is suitable for you and will not interfere with your activities.

Activity Diary:

Please complete the activity diary for the day you are carrying the sampling case. Please complete the form as accurately as possible so that we know at what times the sampling case was in each separate location.

You have been provided with a voice recorder to help you log your activities during the day.

Location Sheet:
For each separate location, you visit and journey you take while you are carrying the sampling case please complete a location sheet. This provides us with useful information about where the sampling case has been taken.

Sampling Day Questionnaire:
Please complete the sampling day questionnaire at the end of each sampling day. This provides us with information about what sort of activities you have been doing and what products you have used so that we can see what you and the sampling case have been exposed to.

Environmental Tobacco Exposure questionnaire:
If you come into contact with someone that is smoking or visit a place where tobacco is smoked, please fill this questionnaire, so we can understand your exposure to tobacco.

Payment

If you encounter any problems with either the sampling equipment or any of the activities or forms we ask you to complete during your sampling period, please contact a member of the research team on [redacted]. Please use the mobile number below if you need to contact a researcher out of office hours during your sampling period.

Name of Researcher:_____ Mobile Number:_____

HEI Project- ACTIVITY DIARY

Volunteer ID | | Date: | |

Time	Where are you?	What are you doing?	Are there any windows or doors open? Y/N	Anyone smoking? Y/N	Location number for		Level of exercise			
					Places visited	Travelling	Rest	Low	Med	High

NOW PLEASE COMPLETE A LOCATION SHEET FOR EACH PLACE VISITED AND EACH TIME YOU TRAVELLED

HEI Project

Location Sheet for in Transit Locations

	Volunteers ID			Measurement Date	
Location number	1	2	3	4	5
Length of time travelling? (e.g. 30mins)					
Start time of travelling?					
If return journey along same route, what time is return?					
Where are you travelling from?					
Where are you travelling to?					
How are you travelling?					
Car/Taxi	☐	☐	☐	☐	☐
Motorbike	☐	☐	☐	☐	☐
Bus	☐	☐	☐	☐	☐
Electric Train	☐	☐	☐	☐	☐
Diesel Train	☐	☐	☐	☐	☐
Metro/Underground	☐	☐	☐	☐	☐
Cycling	☐	☐	☐	☐	☐
Walking	☐	☐	☐	☐	☐
How busy are the roads?					
Not busy *(very few cars around)*	☐	☐	☐	☐	☐
Busy at times *(busy on some roads)*	☐	☐	☐	☐	☐
Busy *(constant moving traffic)*	☐	☐	☐	☐	☐
Very busy *(congested/stationary traffic)*	☐	☐	☐	☐	☐
Not Applicable (travelling by train/metro)	☐	☐	☐	☐	☐
Is anyone smoking?					
No *(not smoky at all)*	☐	☐	☐	☐	☐
Occasionally *(slightly smoky)*	☐	☐	☐	☐	☐
Frequently *(smoky)*	☐	☐	☐	☐	☐
Constantly *(very smoky)*	☐	☐	☐	☐	☐
Please name the areas travelled through or the bus or train route taken: (e.g. Harborne-Edgbaston-City Centre, Bus Number 22, Train Route - Cross City Line - New Street to Erdington, e.t.c.)					

Location number (continued from previous page)	1	2	3	4	5
Please name the roads travelled along: (e.g. Hagley Road-Broad Street-Queensway-A38M-A38 Tyburn Road e.t.c.)					
If you are travelling by car, taxi or motobike please complete the following questions:					
Are you:					
Driving	☐	☐	☐	☐	☐
Passenger	☐	☐	☐	☐	☐
Do you own the car/motorbike?					
Yes	☐	☐	☐	☐	☐
No	☐	☐	☐	☐	☐
Make of car/motorbike?					
Model of car/motorbike?					
Fuel type:					
Petrol	☐	☐	☐	☐	☐
Diesel	☐	☐	☐	☐	☐
Engine size					
Year of manufacture					
Is the air conditioning used?					
Yes	☐	☐	☐	☐	☐
No	☐	☐	☐	☐	☐
Is the fan/heater used?					
Yes	☐	☐	☐	☐	☐
No	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐
Any other information you would like to tell us about:					

HEI Project

Location Sheet for Static Locations

	Volunteers ID:			Measurement Date:		
Location number	1	2	3	4	5	Locatio
Name of location						Name o
Length of time you were at the location.						Length locatio
Floor level:	(tick for the room where you spend most of the time - if you spend time in other rooms tell us in the box at the end of the sheet for additional information)					Floor le
Basement	☐	☐	☐	☐	☐	Basemer
Ground Floor	☐	☐	☐	☐	☐	Ground
1st Floor	☐	☐	☐	☐	☐	1st Floo
2nd Floor	☐	☐	☐	☐	☐	2nd Floo
3rd Floor	☐	☐	☐	☐	☐	3rd Floo
Other	☐	☐	☐	☐	☐	Other
What direction does the location face?	(tick for the room where you spend most of the time - if you spend time in other rooms tell us in the box at the end of the sheet for additional information)					What d
Street	☐	☐	☐	☐	☐	Street
Back Garden	☐	☐	☐	☐	☐	Back Ga
Side/Side Alley	☐	☐	☐	☐	☐	Side/Sid
Car Park	☐	☐	☐	☐	☐	Car Park
Park	☐	☐	☐	☐	☐	Park
Private Road	☐	☐	☐	☐	☐	Private F
Has anyone smoked in this location?						Has an
No *(not smoky at all)*	☐	☐	☐	☐	☐	No *(not*
Occasionally *(slightly smoky)*	☐	☐	☐	☐	☐	Occasio
Frequently *(smoky)*	☐	☐	☐	☐	☐	Frequen
Constantly *(very smoky)*	☐	☐	☐	☐	☐	Constan
What is the name of the road the location is on?						What is locatio
What area is this location in? *(e.g. Edgbaston, Northfield e.t.c.)*						What a *Edgbast*
What is the distance to this road from the location?						What is the loc
Less than 10m	☐	☐	☐	☐	☐	Less tha
10-100m	☐	☐	☐	☐	☐	10-100m
More than 100m	☐	☐	☐	☐	☐	More tha

How busy is this road at the time you are there?						How bu are the
Not busy *(very few cars around)*	☐	☐	☐	☐	☐	Not busy
Busy at times *(busy at certain times)*	☐	☐	☐	☐	☐	Busy at t
Busy *(constant moving traffic)*	☐	☐	☐	☐	☐	Busy *(co*
Very busy *(congested/stationary traffic)*	☐	☐	☐	☐	☐	Very bus
Are there any: (tick if yes)	Yes How many?	Yes How many?	Yes How many?	Yes How many?	Yes How many?	Are the
Photocopiers	☐ _____	☐ _____	☐ _____	☐ _____	☐ _____	Photocop
Printers	☐ _____	☐ _____	☐ _____	☐ _____	☐ _____	Printers
Faxes	☐ _____	☐ _____	☐ _____	☐ _____	☐ _____	Faxes
Does the space have any heating on?	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Does th
Electrical storage heaters	☐	☐	☐	☐	☐	Electrical
Central heating with radiators	☐	☐	☐	☐	☐	Central h
Warm air central heating	☐	☐	☐	☐	☐	Warm ai
Individual heaters	☐	☐	☐	☐	☐	Individua
Others	☐	☐	☐	☐	☐	Others
Is there any other relevant information you would like to tell us about this location?						Is there informa

TOBACCO SMOKE QUESTIONNAIRE

VOLUNTEERS ID: | MEASUREMENT DATE

TIME OF EXPOSURE: e.g. 3pm – 4pm _____

WHEN YOU ARE EXPOSED TO PEOPLE SMOKING PLEASE COMPLETE ONE OF THESE FORMS

PLEASE COMPLETE THE FOLLOWING TABLE:

How far was the smoker from you?	How many people were smoking?	Approx how many cigarettes were smoked?	How long were you exposed to the smoke for?
Less than 2 metres			
More than 2 metres			

2) WHO WAS THE SMOKER?
A FRIEND OR RELATIVE IN MY COMPANY
A PERSON WHO WAS NOT IN MY COMPANY
A PASSER BY

3) WHERE WERE YOU EXPOSED TO THE SMOKE?
OUTSIDE, IN AN OPEN SPACE
INSIDE, IN AN ENCLOSED SPACE
OTHER, PLEASE DESCRIBE _____

FOR OPEN SPACES:

4) IF YOU WERE IN AN OPEN SPACE PLEASE DESCRIBE IT:
PRIVATE GARDEN
PARK
PLAYGROUND
STREET
BUS STOP
OTHER, PLEASE DESCRIBE
_____

5) HOW LONG WERE YOU IN THE OPEN SPACE?
(e.g. 3pm – 4pm)

FOR ENCLOSED SPACES:

6) IF YOU WERE IN AN ENCLOSED SPACE
PLEASE SAY WHERE YOU WERE:

7) HOW SMOKY IS THE ROOM?
NOT SMOKY AT ALL
SLIGHTLY SMOKY, PEOPLE ARE SMOKING OCCASSIONALLY
SMOKY, PEOPLE ARE FREQUENTLY SMOKING
VERY SMOKY, THERE ARE PEOPLE CONSTANTLY SMOKING

8) HOW VENTILATED IS THE ROOM?
IT IS WELL VENTILATED
THERE IS SOME VENTILATION
IT IS NOT VENTILATED

I DON'T KNOW

9) ARE THERE ANY SOURCES OF VENTILATION IN THE ROOM?
OPEN WINDOWS
OPEN DOORS
FAN
CEILING FAN
AIR EXTRACTORS
AIR CONDITIONING
PASSIVE VENTILATION
DON'T KNOW

10) WHEN YOU WERE EXPOSED TO THE SMOKE WERE ANY HEATING SOURCES ON?
YES
NO
DON'T KNOW

HEI Project- Sampling Questionnaire

Volunteer ID _____ Measurement Date _____

Activities	Please Tick used sampling		Specify the activity you are doing	For how long?	What products are you using?	What is your location?	Is there any ventilation?		Level of exercise			
	day	week					Yes	No	Rest	Low	Med	High
Cleaning	☐	☐										
Dusting *(e.g. furniture polish)*	☐	☐										
Vacuuming	☐	☐										
Dry cleaning	☐	☐										
Candle burning	☐	☐										
Use of a photocopier, printer and faxes	☐	☐										
Use of fireplace	☐	☐										
Use of any other fossil fuels *(e.g. petrol lawn mower)*	☐	☐										
Visit to petrol station/refuelling car	☐	☐										
DIY - Painting	☐	☐										
DIY – Other *(please specify)*	☐	☐										
Gardening *(e.g. lawn mowing)*	☐	☐										
Not Applicable - non of above activities done.	☐	☐										

Researcher use only
ID Code:

WITHDRAWAL FORM

HEI Project – Use of real-time sensors to assess misclassification and to identify main sources contributing to peak and chronic exposures

I no longer wish to participate in the HEI Project and I would like that the following information is deleted from the database of the study:

Information provided in questionnaires:
Screening Questionnaire Information
Activity Diary Information
Sampling Day Questionnaire Information
Locations Sheet for Static Locations Visited during Sampling Day Information
Location Sheet for In-Transit Locations Information
Environmental Tobacco Exposure Questionnaire Information
Home baseline Questionnaire Information

Information provided by the samplers:
Personal Exposure concentrations
Home Exposure concentrations
GPS track logs
Accelerometer data

NAME OF VOLUNTEER SUBJECT: .....

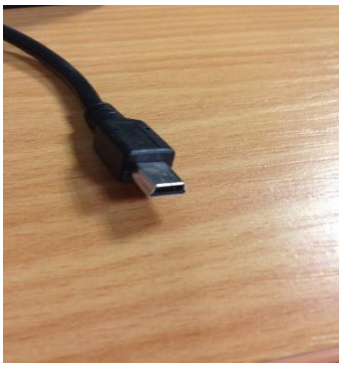
SIGNATURE: .....

DATE: .....

Sensors and Chargers photos

MicroPem


MicroAeth

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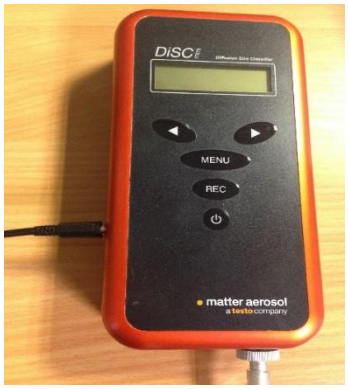
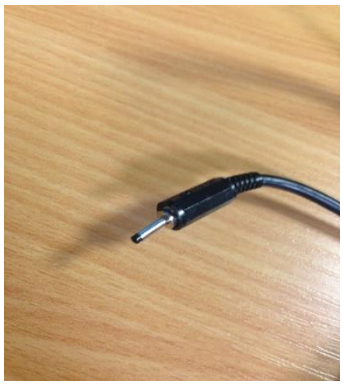





Standard operating procedure (SOP)

STANDARD OPERATING PROCEDURE

FOR SUBJECT SCREENING AND SAMPLING VISITS

2011 WALTER ROSENBLITH PROJECT

	Prepared by	Reviewed by	Approved by
Name	Dr. Juana Maria Delgado Saborit		
Date	22nd February 2013		

Table of Contents Page

1 Scope and Application

This Standard Operating Procedure should be followed when visiting the volunteers for both screening and sampling purposes.

2 Summary of the Method

The procedure describes the protocol to be followed when visiting the volunteers for both screening and sampling purposes.

3 Health and Safety Warnings

The main identified risks are:

- use of air monitoring equipment – electrical equipment/moving parts etc;
- carrying the microenvironment boxes to and from people's homes (researchers), and - - carrying the personal sampler (participants) - Manual lifting and handling
- driving to and from participant's homes and offices – traffic (researcher)
- working in urban areas (researcher) – traffic/mugging;

- working in other people's homes/offices (researcher) – poorly maintained floors stairs – slipping/falling/tripping – electricity
- working with unknown subjects (researchers) – mugging/personal security.

The proposed measures are:

- When working in urban areas and driving to and from participants homes extra care should be taken;
- Extra care should be taken when handling electrical equipment and this would be PAT tested;
- Equipment should be carried properly to avoid straining and injury;
- Participants homes should be carefully checked and the best location chosen for the microenvironment box to discourage tampering, avoid small children or busy walkways etc,
- Participants should be informed not to tamper, move or open either personal sampler or microenvironment box;
- Personal sampler and microenvironment box should be locked when left with participant;
- Equipment warning sheets should be attached to the personal sampler and microenvironment box when they are with a participant to reduce tampering. Warning sheets should also contain a contact number so the research team can be contacted at anytime;
- The condition of participants homes should be noted in the screening visit and extra care should be taken during sampling to avoid any problems or injury which may results from poorly maintained floors or stairwells;
- Keep a log of the participant's information (name and address) during the sampling period that the researcher is in contact with the participant, and follow a protocol of calling a second researcher informing of the timing that the research in charge visits each participants, before and after entering the participant's home.

4 Personnel Qualifications

The researcher should be trained at least once in the protocol described in this SOP before

initiating the procedure alone.

5 Abbreviations used

SOP Standard Operating Procedure

PE Personal Exposure

ME Microenvironment

Screening visit

- Equipment Needed:
Personal Sampling Case

Volunteers Consent Form

Volunteers Screening Questionnaire

Screening Visit Folder containing:

- Participant Information Sheet
- Contact Sheet
- Instruction Sheet
- Activity Diary
- Location Sheet for Travelling

Location Sheets for Places Visited

- Sampling Questionnaire

ETS Questionnaire

Participant Baseline Questionnaire

Withdrawal form

- Sampling Certificate
- Volunteer ME Box Photos
- Samples of Expense Forms

- Procedure:

- The screening visit should be arranged with the volunteer preferably at their home and should last between 30 minutes and 1 hour.
- Start the screening visit by explaining the purpose of the study to the volunteer – remember that they should have read the participant information sheet.
- Stress the importance of them leading their daily life as usual and that no changes in this are required for the study.
- Show the volunteer the PE case. Open the case up and explain contents.
- Discuss the daily visit from the researcher. Explain the purpose of this visit in relation to the PE case and the importance of visiting them in the afternoon or early hours of the evening.
- Address any concerns they may have about the daily visits should they arise.
- Turn the case on to give the volunteer an indication of the noise level the case produces. Make sure the volunteer is happy with everything that has been explained and with the noise level.
- Show the volunteer the ME photos. Explain the contents and the noise level and make sure they are happy with the noise level and the explanations.
- Explain the microenvironment sampling in their homes. Address any concerns they may have.
- Show the volunteer the instruction sheet for their sampling days. Go through the instruction sheet with them.

- Explain the activity diary, its purpose and when they would need to complete it each day.
- Explain the sampling day questionnaire, its purpose and when they would need to complete it each day.
- Explain the location sheets, their purpose and when they would need to complete them each day.
- Answer any further questions the volunteer may have.
- Make sure they are still happy to participate in the study.
- Remind them that we will pay them £15 for each day of sampling they complete, and that they will receive this money by completing the finance form after sampling has concluded, which will them be processed by our finance department and the money will be paid directly into their account.
- If they are still happy to participate sign their consent form which they should have returned, if they have not returned a consent form ask them to sign one and the researcher should countersign.
- Ask them for an approximate month that would be suitable for them to do the sampling.

Sampling Visit

- Equipment Needed:
See SOP SAM PE and SAM ME

PE and ME case

Volunteers study booklet

University finance form to request payment of £50 fee (Friday only)

- Procedure:
See SOP SAM PE and SAM ME for the procedure for preparation of equipment, setting up of equipment at the volunteers homes and procedure for return of equipment and samples to the University.

Sampling Day 1 (Monday)

- The sampling days should be arranged with the volunteer for a date suitable for them. The days which the microenvironment samples will be taken should be arranged prior to the sampling to make sure everything is suitable for them.
- A courtesy call should be made to them on the Thursday before sampling is due to start to make sure that the date arranged is still suitable, to check the meeting time arranged and to make sure that they are expecting us.
- Start the visit on the first day of sampling by setting up the sampling equipment using SOP SAM PE. Make sure this is working correctly.
- Answer any questions the volunteer has about the sampling equipment once it is set up.
- Give the volunteer their study booklet (containing our contact information, their instruction sheets, 5 activity diary forms, 5 travel and 5 places visited location sheets, 5 sampling questionnaire forms, 5 ETS forms and a baseline questionnaire.
- Go through each step of the instruction sheet with them.
- Explain how and when they need to complete the activity diary, the location sheets and the sampling day questionnaire.
- Explain the weekly timetable.

- Explain to the volunteer how to carry the case – with the black stoppers facing away from their body, not to block the inlets, not to place the case near open windows/doors or heat sources unless they themselves are next to these.
- Ensure that the volunteer is completely happy with the PE and ME sampling case and the forms before the sampling visit is concluded.
- Arrange time for visit the next day.

Sampling Day 2-3 (Tuesday and Wednesday):

- Follow SOP SAM PE procedure for equipment.
- Ask the volunteer if they are having any problems with the sampling case or forms they have to fill in.
- Check the activity diary forms, location sheet forms and sampling day questionnaire forms to ensure they have been completed correctly. If not go through explanation of the forms again with the volunteer.
- Answer any questions the volunteer raises.

Sampling Day 4 (Thursday):

- Follow SOP SAM PE procedure for equipment.
- Ask the volunteer if they are having any problems with the sampling case or forms they have to fill in.
- Check the activity diary forms, location sheet forms and sampling day questionnaire forms to ensure they have been completed correctly. If not go through explanation of the forms again with the volunteer.
- Answer any questions the volunteer raises.
- Give the volunteer the appropriate finance form for them to complete for the following day so that their £60 fee can be paid into their bank account. *
- Request a copy of the passport for finance office to process the claim
- Arrange time for visit the next day.

Sampling Day 5 (Friday):

- Follow SOP SAM PE procedure for equipment.
- Remove the ME home sampling case and the PE sampling case using the SOP procedure.
- Ask the volunteer if they are having any problems with the sampling case or forms they have to fill in.
- Check the activity diary forms, location sheet forms and sampling day questionnaire forms to ensure they have been completed correctly. If not go through the forms with the volunteer and fill them in correctly.
- Answer any questions the volunteer raised.
- Collect completed expenses form from volunteer.

Thank the volunteer for their time and effort in the study and ensure they realise that they will receive a copy of their results at the end of the study.

Monday after Sampling:

- Pass volunteers completed finance form to Juana Mari for processing

University Finance Forms

- For the general public (not involved with the University) use a FIN 14 (green form). Under reason for non-deduction of Tax and National Insurance please write in large letters – VOLUNTEER.
- For students of the University use a FIN 15 (blue form). Under forms completed for non-deduction of Income Tax please write in large letters – VOLUNTEER.
- For members of staff use a FIN 16 (grey form). Under purpose for which expenditure was incurred please write in large letters – VOLUNTEER NOT LIABLE FOR TAX.

Please see examples with paper copy of SOP – located in the filing cabinet in room 306.

STANDARD OPERATING PROCEDURE

FOR GRAVIMETRIC DETERMINATION OF FILTERS

2011 WALTER ROSENBLITH PROJECT

	Prepared by	Reviewed by	Approved by
Name	Dr. Juana Maria Delgado Saborit		
Date	22nd February 2013		

Table of Contents Page

1 Scope and Application

This procedure is used as the SOP for weighting filters

2 Summary of Method

The procedure describes the protocol to condition filter prior to weighing, the procedure to weighing filters and the associated records.

3 Health and Safety Warnings

The main health and safety issue with the weighing is related to using radioactive materials. The measures to reduce risks are:

- Always use gloves and protective clothes.

- Never touch the Polonium 210 alpha source strip with your hands or skin

- Keep the Polonium 210 alpha source strip safely stored in the safety cabinet before and after the weighing procedure.

4 Personnel Qualifications

The researcher should be trained at least once in the protocol described in this SOP before initiating the procedure alone.

5 Equipment and Supplies

- Clean tweezers

- Petri dishes

- Labels

- Aluminium foil

- Microbalance

- Ioniser blower

- Polonium 210 alpha source strip

- Weighing chart

6 Filter Preparation

- Place a piece of baked aluminium foil on the marble table. Baked aluminium foil does not contain carbon and can be used as a working surface when handling filters. Although you should not place - your filters on the foil directly, in case filters do drop on the baked foil, it will not collect dust from the table surface.
- Label the same amount of petri dishes as filters you want to measure
- Place the labelled petri dishes on top of the aluminium foil.
- Filters should be examined for defects and irregularities. Only good filters should be used for weighing and subsequent sampling.
- Place the filters inside the petri dishes, and cover partially each petri dish with the petri dish cap.

- The filters should be conditioned in the weighing room for at least 24 hours before they are weighed for both the initial and final weighing.
- Filters should always be handled with clean tweezers to avoid contamination. Filters should not be turned upside down.
- The same filters should be weighed in the same balance and by the same operator weighing the initial weights. It has been shown the filter weights vary by the operator weighing the filters.

7 Balance preparation

- The balance is set to remain on all the time so it is always ready for usage.
- Re-zero the balance when you're ready to start (this takes the balance off the "Standby" setting) and wait until it stabilizes to zero. (It usually takes around 15-20 minutes.) If the balance is turned OFF, after it is turned ON, it will take 60 minutes before it goes through the internal calibration and stabilizes and it will take approximately 2 hours before you can start taking the first weight. When moving the balance from one location to the other, it will take 6 to 12 hours for the balance to acclimatize depending on the temperature difference between the old and the new location.
- Look at the air bubble on the top of the weighing cell to make sure the balance is level. If the bubble is not in the middle of the circle, turn the two screws feet at the rear of the weighing cell housing until the air bubble is in the middle.
- You want to make sure that you are weighing on the FINE MODE of the balance. This can be checked by counting the number of zeros after the decimals to be six. If you are on the COARSE mode, press "10/1 µg" to return to the FINE MODE.

8 Static Charge removal preparation

- Teflon filters accumulate a surface electrical charge that has been shown to cause the weight on the filter to not stabilize during weighing. Each filter should be passed over a Polonium 210 alpha source strip to remove static charge before weighing.
- Switch on the ioniser blower
- Collect the Polonium 210 alpha source strip from the security cabinet
- Place the Polonium 210 alpha source strip inside the top of the weighing carrousel of the balance

9 Procedure to weigh filters

- Filters should be handled with a clean pair of tweezers by their edge and care should be taken not to tear them or damage them. If a tear occurs, do not use the filter in the field or in the lab for sampling.
- Press “Select 1” to open the draft shield.
- By using a clean pair of tweezers, hold the filter for a few seconds at about 1 inch (2.5 cm) distance from the ionization strip to remove static charge.
- Then place the filter on the weighing pan located inside the weighing cell and wait for the balance to stabilize. During this process, the sliding door should remain closed.
- Record the filter weight on the logbook/logsheets.
- Tare the balance with the filter in position
- Take the filter out from the pan and place it inside the petridish.
- Record the filter weight on the logbook/logsheets (should be negative value)
- Tare the balance with no filter in position
- Check the balance again with no filter inside and with the draft shield closed to see if it has gone back to zero. A reading of ±0.000001 is acceptable. If the balance displays a reading outside this range, re-zero the balance and reweigh the filter by repeating steps 5-10 until the weight meets the specifications.
-Each filter should be weighed trice. Accept the weights if the measurements are within 5 micrograms; otherwise, measure the filter a fourth time and accept the closest three of the four measurements. Record all weights in the “Weighing Logsheet” provided at the end of this protocol.
- While weighing, make sure not to put pressure on the table, as the additional weight skews the balance reading.

10 Filter Storage

- After weighing, the filters are kept in their respective petridishes or cassettes.
- Store the filters in an appropriate drawer ready for sampling or stored the filters in the freezer for archiving or future analyses after sampling.

STANDARD OPERATING PROCEDURE

FOR OPERATING THE MICROAETHALOMETER

2011 WALTER ROSENBLITH PROJECT

	Prepared by	Reviewed by	Approved by
Name	Dr. Juana Maria Delgado Saborit		
Date	24th July 2013		

Table of Contents Page

1 Scope and Application

This document describes the instructions to operate the MicroAethalometer

2 Summary of Method

The procedure describes the protocol to prepare the microAethalometer for sampling, download and check the data collected by the sensor and to remove the filter.

3 Health and Safety Warnings

The main health and safety issue with the sensor is related to using electric equipment. The measures to reduce risks are:

- Use a protective socket for both personal protection and site operation.

- Handle electrical leads and connections only if they are disconnected from the power supply

- Protect cable connections from water and bad weather

- Check all the electrical equipment before taking it to the field

4 Personnel Qualifications

The researcher should be trained at least once in the protocol described in this SOP before initiating the procedure alone.

5 Equipment and Supplies

- MicroAethalometer

- USB connection

- Clean filter tickets

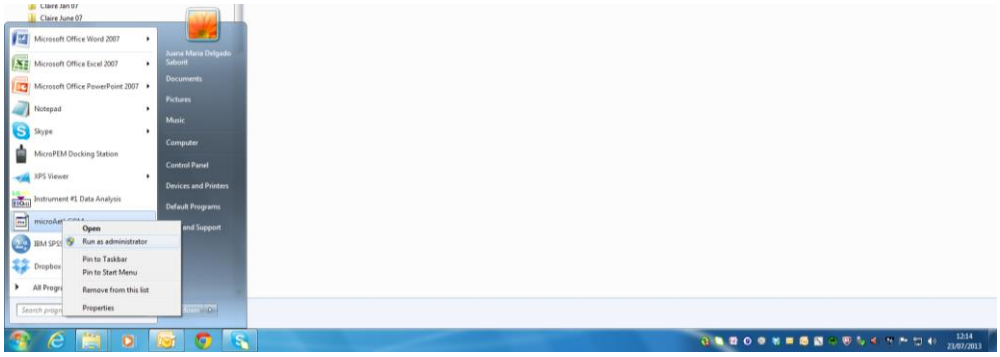
6 Download the data from the sensor

- Make sure that the aethalometer has a filter ticket inside. Otherwise follow the steps “Insert a filter ticked listed below”

- Switch on the aethalometer

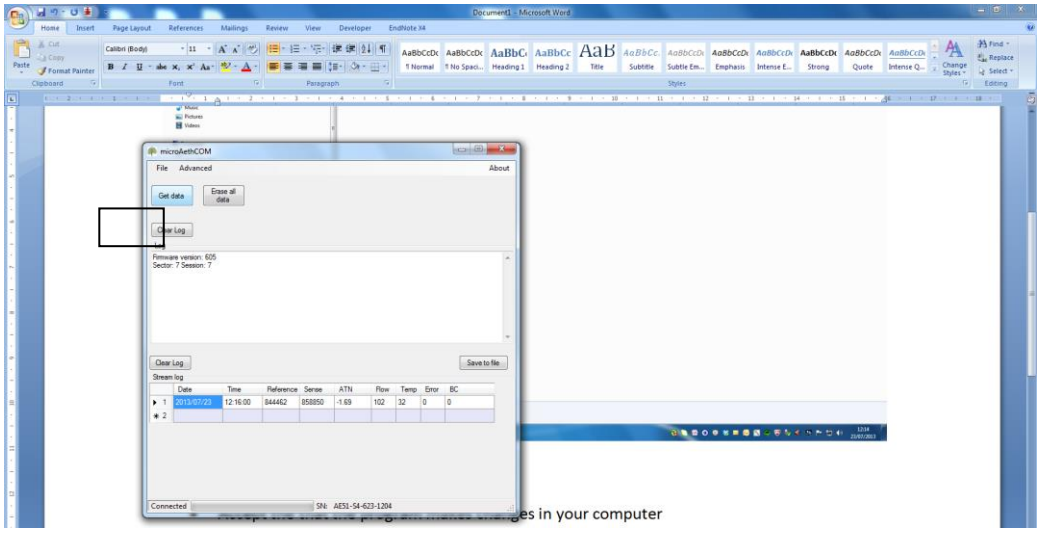
- Connect the running aethalometer to the computer using the USB connection.

- Select the program MicroaethCOM>right click with the mouse>run as administrator



- Accept that the program makes changes in your computer (i.e. run as administrator)

- Press Get Data

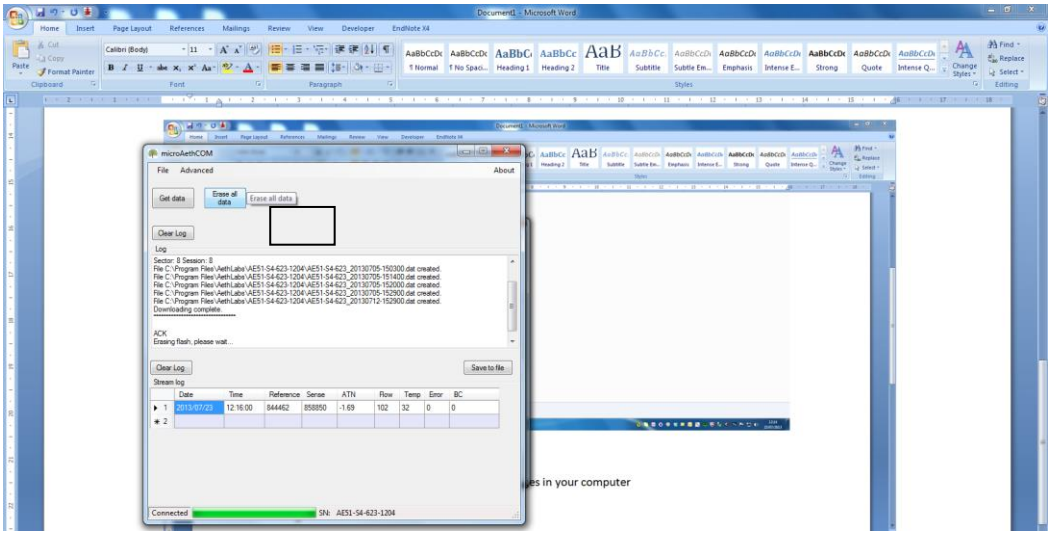


- Select the appropriate folder where you want to save the data. The archive folder is located in the dropbox folder Validation. To find the appropriate folder they are organised as:

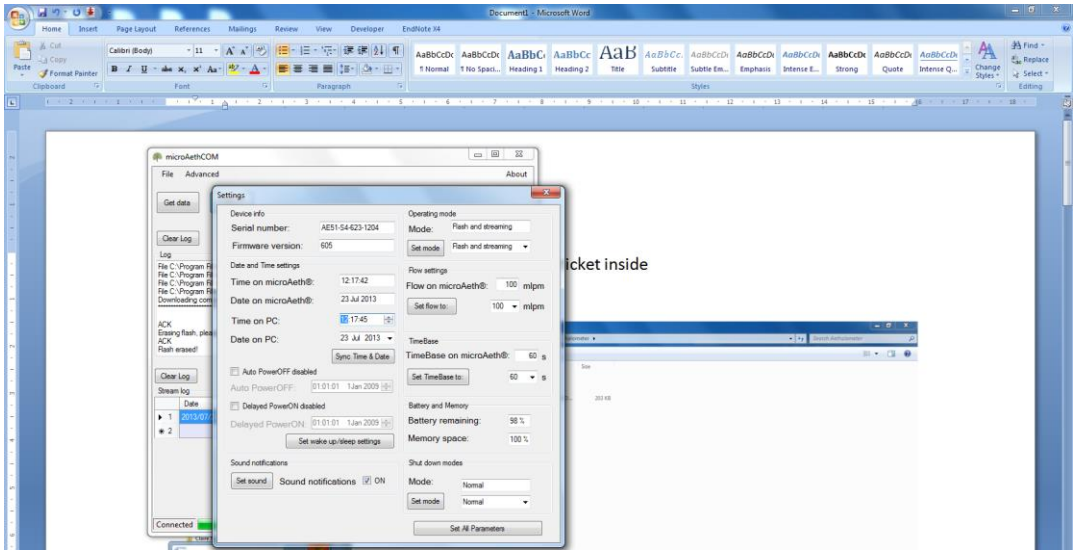
- Season>Station>Pollutant>Sensor No

- Once download has been completed, check that the data file is in your computer.

- Once data has been downloaded, Erase all data



- Check the sensor settings: File>Device Settings

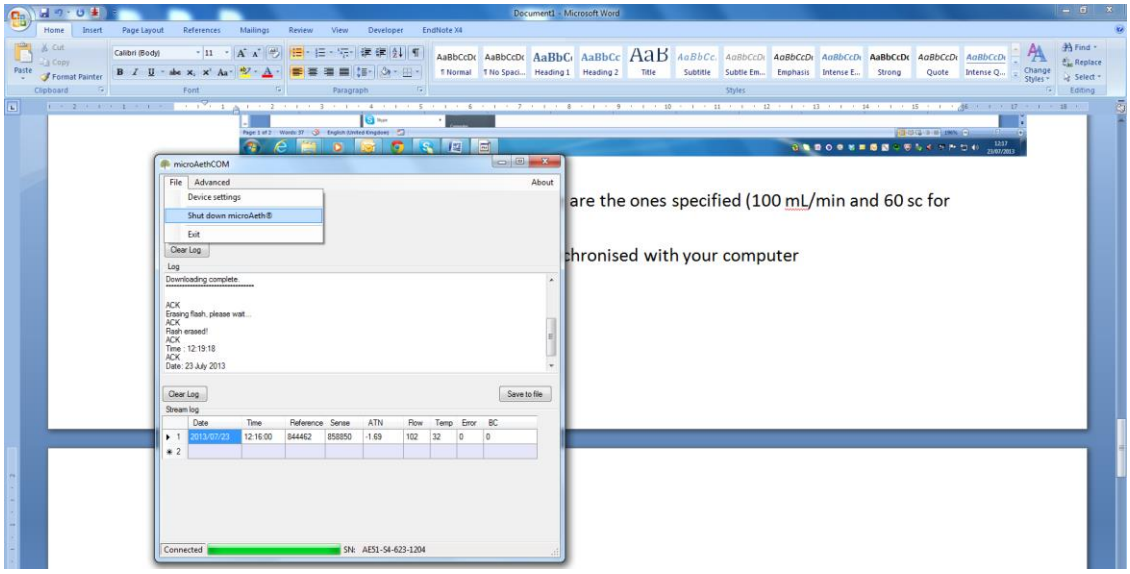


- Make sure that the flow rate and time base are the ones specified (100 mL/min and 60 s for validation, 300 s for sampling).

- Make sure that the clock and date are synchronised with your computer. Otherwise press “Sync Time & Date”

- If you don’t make any changes, click the red arrow right top. Otherwise set the specified parameter to your required output.

- After you have finished, shut down the microaethalometer



7 Copy the downloaded data into the appropriate folder

- The folders are located in C:\Program Files\AethLabs

- Select the folder corresponding with the serial number of the aethalometer

- Sort by date the files

- The downloaded data will appear under the data of today

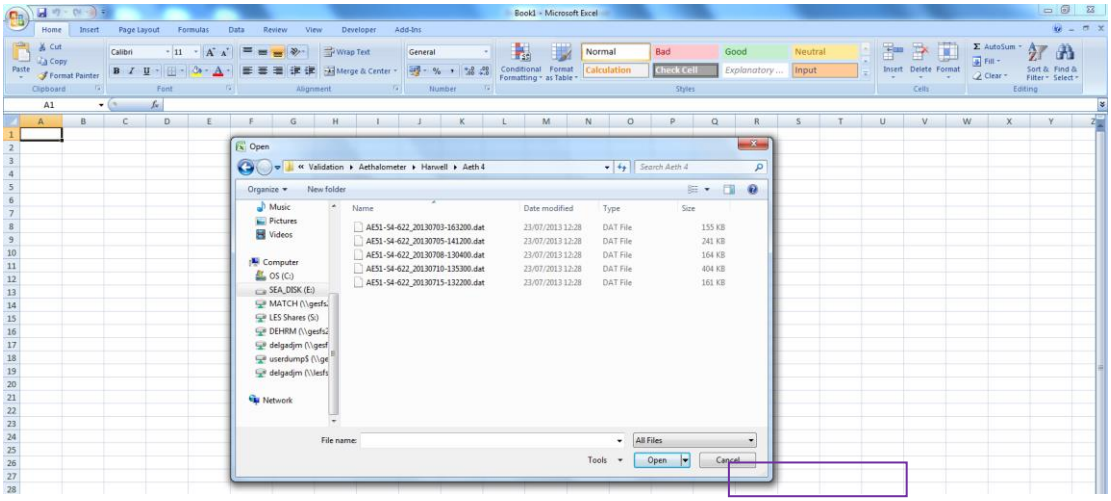
- Copy those files and paste them in the appropriate folder in the dropbox according to season, location and sensor number within the microAeth folder.

8 Open the *.dat files

- Open excel

- Open file> select the location where your files are stored

- Select “All Files”



- Select file of interest and click Open>Delimited>NEXT>Semicolon>FINISH

- The data files contain the following information:

AethLabs
Device ID = AE51-S4-622-1204
Application version = 1.2.0.1
Flow = 100 mlpm
TimeBase = 59 s

Date(yyyy/MM/dd)	Time	Ref	Sen	ATN	Flow	Temp	Status	Battery	BC
15/07/2013	13:22:00	793027	906299	-13.35	99	49	0	100	
15/07/2013	13:22:59	803866	918136	-13.29	100	50	0	100	3460
15/07/2013	13:23:59	803935	918231	-13.29	99	50	0	100	-103
15/07/2013	13:24:59	803991	918267	-13.29	100	50	0	100	176
15/07/2013	13:25:59	803695	918705	-13.37	100	50	0	100	-4882

- Charge for 24 hours before hand it to the subject

9 Insert a new filter ticket into the sensor

Top view

Bottom view

White side of filter strip is sample deposit side. White side faces up.

Metal side of filter strip faces bottom.

Install filter strip. Left thumb is pressing release button on bottom.

Section A: Install/Exchange Filter Strip

1. The sample deposit side of the filter strip is the white side. When the filter strip is installed in sample chamber, the white side of the filter strip should be facing the same direction as indicated by the white arrow on the face plate of the microAeth.
2. Hold the microAeth in your left hand, with the release button on the lower side.
3. Loosen the rubber cover on the front of the microAeth by pulling the tab away from the instrument. This will expose the filter strip slot.
4. Note that the locating pin in the sampling head will be on the lower side of the sample chamber.
5. If there is a filter strip already installed, depress the release button with your left thumb, press the used filter strip up against the lower side of the sampling head to disengage the filter strip from the locating pin, then pull it out.
6. Install a new filter strip by pressing the release button and then inserting the new filter strip into the sample chamber opening.
7. Make sure to press the new filter strip against the lower side of the sampling head to slide it over the locating pin until the hole is aligned, then lower it onto the pin.
8. Release the button.
9. Replace the rubber cover. A tight fit is essential to prevent the entry of contamination and stray light into the sample chamber.

10

If you require further information (e.g. error codes), please check the manufacturer manuals:

- microAeth® Model AE51 Operating Manual - microAeth® Model AE51 Quick Start Manual

STANDARD OPERATING PROCEDURE

FOR OPERATING THE MICROPEM

2011 WALTER ROSENBLITH PROJECT

	Prepared by	Reviewed by	Approved by
Name	Dr. Juana Maria Delgado Saborit		
Date	24th July 2013		

Table of Contents Page

1 **Scope and Application**

This document describes the instructions to operate the MicroPEM

2 Summary of Method

The procedure describes the protocol to prepare the microPEM for sampling, download and check the data collected by the sensor and to remove the filter.

3 Health and Safety Warnings

The main health and safety issue with the sensor is related to using electric equipment. The measures to reduce risks are:

Use a protective socket for both personal protection and site operation.

Handle electrical leads and connections only if they are disconnected from the power supply

Protect cable connections from water and bad weather

Check all the electrical equipment before taking it to the field

4 Personnel Qualifications

The researcher should be trained at least once in the protocol described in this SOP before initiating the procedure alone.

5 Equipment and Supplies

MicroPEM

USB connection

Screw driver

Tweezers

2-pin accessory

1 clip accesory

HEPA filter connected to one of the MicroPEM inlets

Pre-weighted filters

Clean petri dishes (where filters were pre-weighted)

4 New coin cells 3V DL2032 (in case of replacement)

12 New AA 1.5 Batteries (in case of replacement)

6 Prepare the MicroPEM for Sampling

- Unscrew the inlet of the sensor

- Place the 2-pin accessory in the inlet

- Turn the sensor and unscrew the back to open the sensor

- Bring the top part to the left. Note: be careful with the leads.

- Take a voltameter (switch at 20) and check the current of the AA batteries and the coin cell (Should be above 1.5)

- Replace the coin cell battery if the voltage is below 2.8 V (above 2.8 V, minimum 2.6)

- Write down the coin cell battery voltage in the MicroPEM Log

- Push the 2-pin accessory to release the filter cassette and remove the cassette using clean tweezers

- Open the filter cassette

- Place a new pre-weighted 25-mm Teflon filter (Pall Corporation Teflo 3 um, 25 mm, P/N R2PI025).

- Note 1: Follow the Weighting SOP to pre-weight the Teflon filters.

- Note 2: Place the filter with the Top facing upwards.

- Note 3: Top of the Teflo filter has a clearly defined ring border

- Place back the cover of the MicroPEM sensor and screw the back screw.

-Remove the 2-pin accessory and place back the inlet of the sensor.

Note 4: The opening of the inlet has to look towards you.

- Screw the inlet in place.

- Write down the filter ID number in the log

7 Check the reading of the sensor in clean conditions

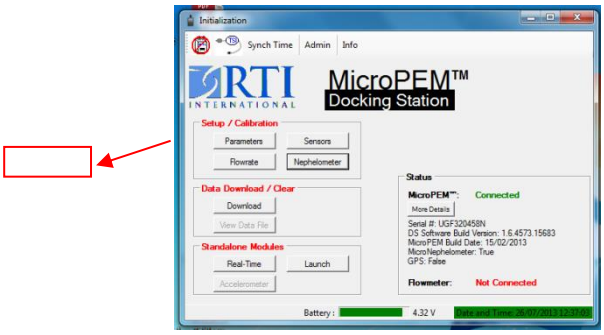
- Connect the microPEM to the computer using the USB drive provided

- Open the microPEM docking station

- Connect the HEPA filter to the inlet.

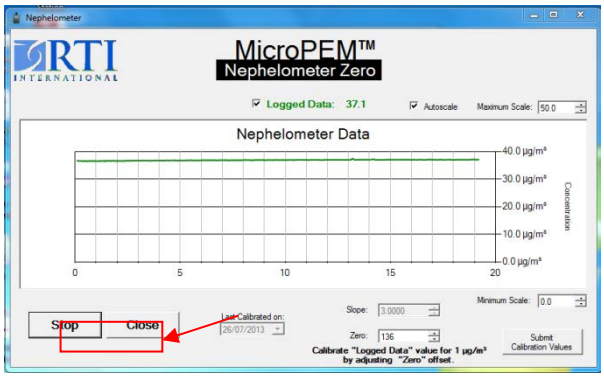
Note 5: Make sure that the tube connecting to the HEPA filter faces the inlet opening

- Open the Nephelometer tab

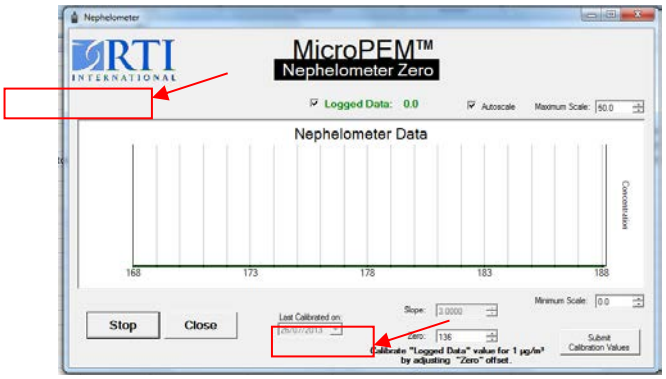


- Click Start and leave it running for at least 1 min to stabilise.

- If the reading of the microPEM is different from 0, then adjust the voltage to ensure a zero reading. For that, press the arrow keys by the ZERO window



- Once the Logged data shows 0 and it is stable (allow 1 min), then press Submit Calibration Values

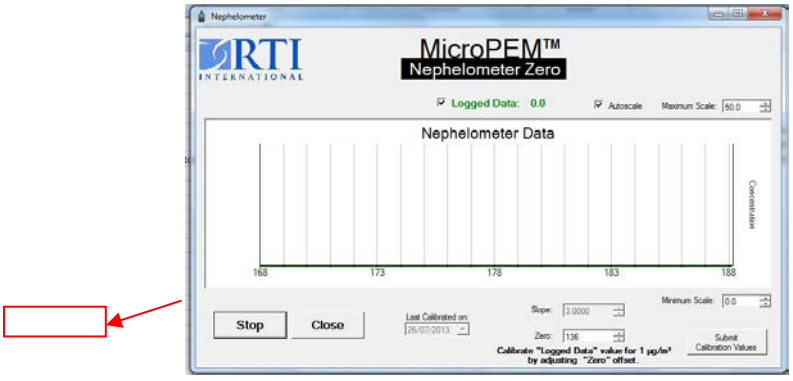


- Make a record of the calibration voltage in the MicroPEM Log.

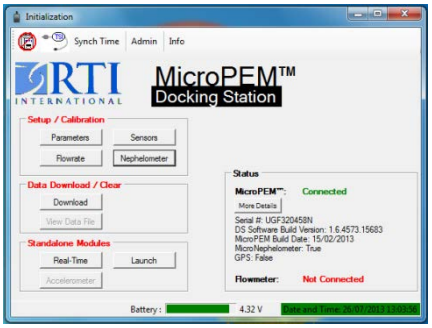
- Remove the HEPA filter

- Connect flowrate (TSI flowmeter), click flowrate, then next and follow instructions. Once finished remove flowmeter.

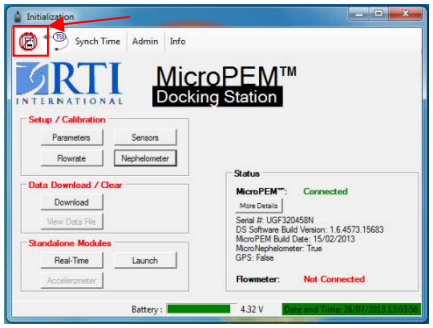
- Close the nephelometer window



- Synchronise the time and date with the computer



- Disconnect the microPEM from the docking station (Click OK and wait until it disconnect)



- To the question, “would you like to clear the data when disconnecting from the docking station?”:

- Reply YES IF you have downloaded the data.

- Reply NO IF you have not yet downloaded the data

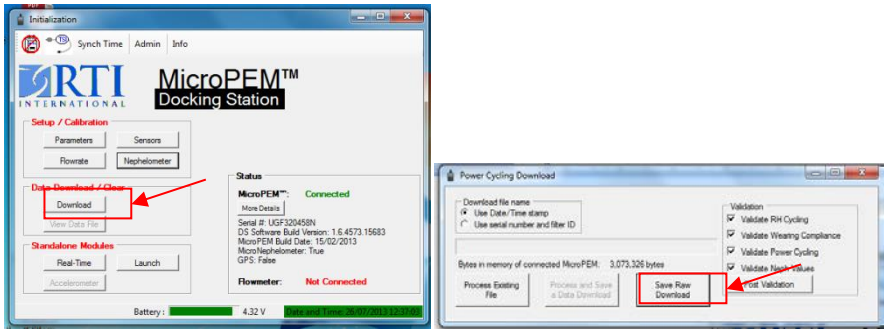
- The MicroPEM is ready to be used.

8 Download the data

- Connect the microPEM to the computer using the USB drive provided

- Open the microPEM docking station (wait until the microPEM connected to the softwear)

- Press Download and then Save Raw Download. Save the file’s type as “All files (*.*)”

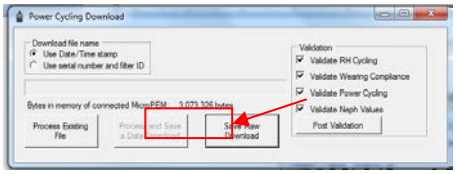


- Select the appropriate folder where you want to save the data. The archive folder is located in the dropbox folder Validation. To find the appropriate folder they are organised as:

- Season>Station>Pollutant>Sensor No

- Once download has been completed, open the existing file by pressing “Process Existing File”

- Check inlet pressure is below 1.4 inches (see the downloaded data in excel sheet).



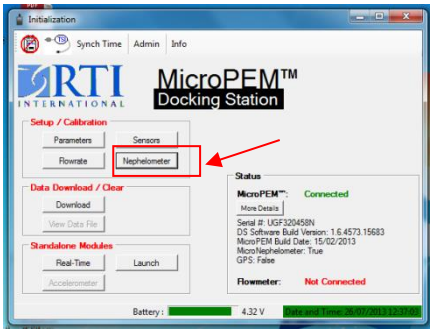
- Review the data for any abnormalities. Check for the time and date stamp according with your expected sampling times.

9 Check the reading of the sensor after sampling

- Connect the HEPA filter to the inlet.

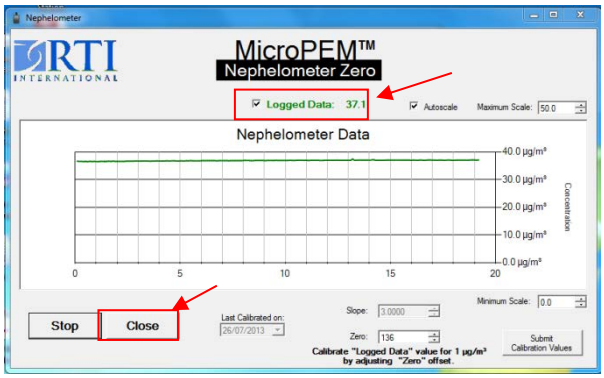
Note 6: Make sure that the tube connecting to the HEPA filter faces the inlet opening

- Open the Nephelometer tab



- Click Start and leave it running for at least 1 min to stabilise.

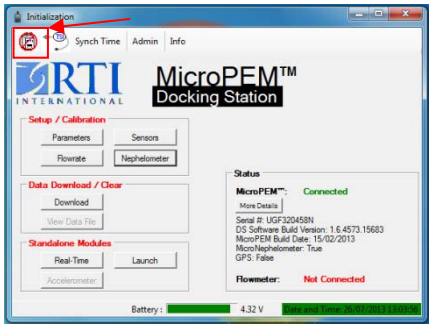
- Record the logged data value into the MicroPEM Log and press Close



- Remove the HEPA filter

- Close the nephelometer window

- Disconnect the microPEM from the docking station



- To the question, “would you like to clear the data when disconnecting from the docking station?”:

- Reply YES IF you have downloaded the data. Wait until data cleared and disconnected

- Reply NO IF you have not yet downloaded the data

10 Remove the sampled filter from the MicroPEM

- Follow steps 1-9 in above.

- Remove the sampled Teflon filter.

- Place the sampled filter in its corresponding labelled Petri Dish.

- Follow steps 10-13 to put a new Teflon filter ready for new measurement.

FOR OPERATING THE ULTRAFINE PARTICLE SENSOR

DISCMINI

A-Starting discmini

-Press ⏻ button (you will see on the screen warming up counting down, this takes 5 minutes)

-After the countdown/ warming up finished, the discmini will make noise, immediately press (REC) button to start recording the measurements, after pressing (REC) button you will see on the upper right corner of the screen a flashing dot, this indicate that the sensor is taking measurements


DiSC mini
Diffusion Size Classifier
MENU
REC


DiSC mini
Diffusion Size Classifier
WAIT 284s WARMUP
+21.0°
MENU
REC
matter aerosol
a testo company


DiSC mini
Diffusion Size Classifier
N 1902 pt
Size 24 nm 19%
MENU
REC
matter aerosol
a testo company


DiSC mini
Diffusion Size Classifier
N 1550 pt
Size 28 nm 19%
MENU
REC
matter aerosol
a testo company

B-Switch off the discmini

Press (REC) button then press ⏻ button to switch the discmini off

STANDARD OPERATING PROCEDURE

FOR DOWNLOADING AND CHECKING THE DATA FROM THE

ULTRAFINE PARTICLE SENSOR DISCMINI

2011 WALTER ROSENBLITH PROJECT

	Prepared by	Reviewed by	Approved by
Name	Dr. Juana Maria Delgado Saborit		
Date	24th July 2013		

Table of Contents Page

1 Scope and Application

This document describes the instructions to download and checking the data of the ultrafine particle sensor DISCmini

2 Summary of Method

The procedure describes the protocol to download and check the data collected by the ultrafine particle sensor.

3 Health and Safety Warnings

The main health and safety issue with the sensor is related to using electric equipment. The measures to reduce risks are:

Use a protective socket for both personal protection and site operation.

Handle electrical leads and connections only if they are disconnected from the power supply

Protect cable connections from water and bad weather

Check all the electrical equipment before taking it to the field

4 Personnel Qualifications

The researcher should be trained at least once in the protocol described in this SOP before initiating the procedure alone.

5 Equipment and Supplies

DISCmini sensor

USB flash disc

Memory card

6 Download the data

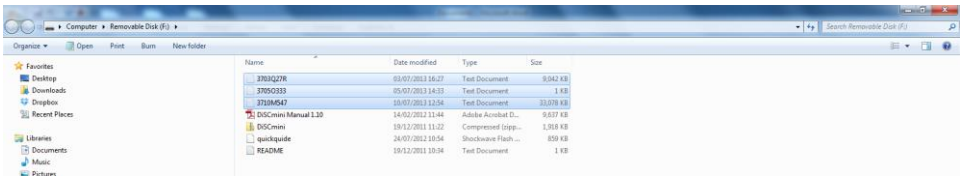
Extract the memory card from the sensor

Insert the memory card in the USB flash disc

Connect to the computer

Open the folder in the removable disk

Cut the TXT document files and place them in the archive folder



The archive folder is located in the dropbox folder Validation. To find the appropriate folder they are organised as:

Season>Station>Pollutant>Sensor No

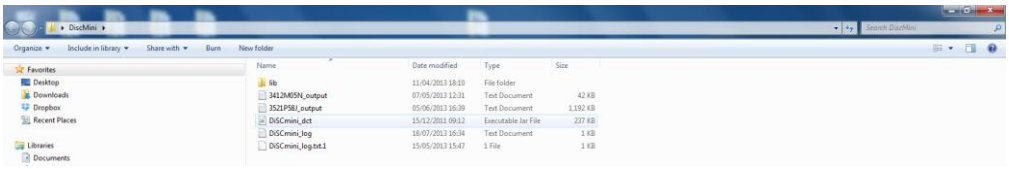
Paste the documents in the appropriate season, station and sensor number of the UFP folder.

Eject the removable disk

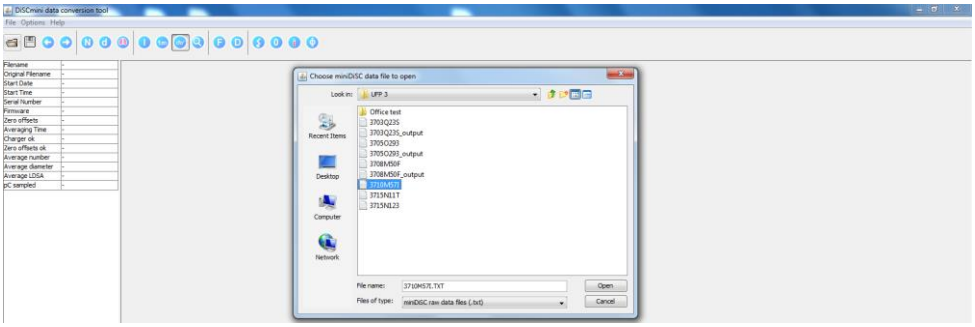
Remove the blue memory scan from the USB drive and install it back to the DiscMini sensor. Note: the golden metal facing upwards.

7 Check the data

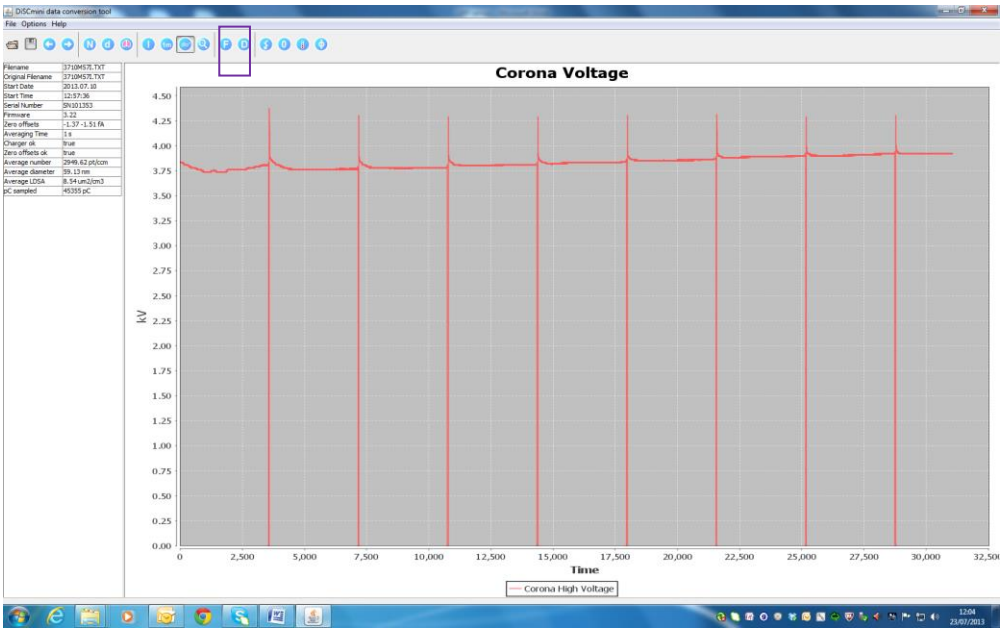
Open the DISCmini Executable DiSCmini_dct

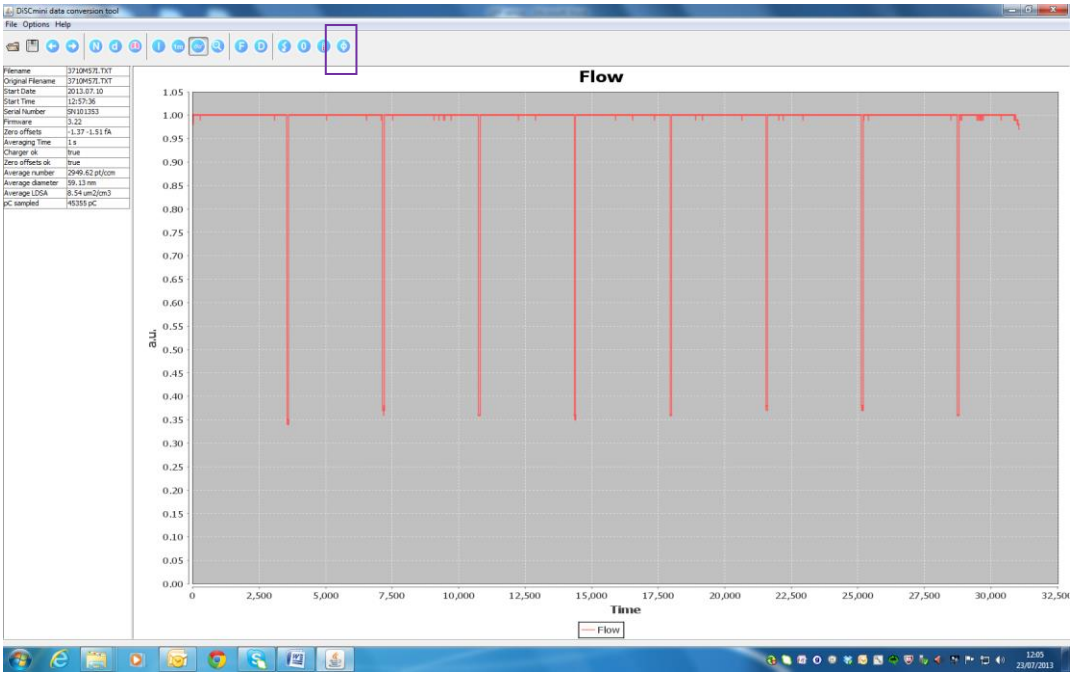


Open file of interest

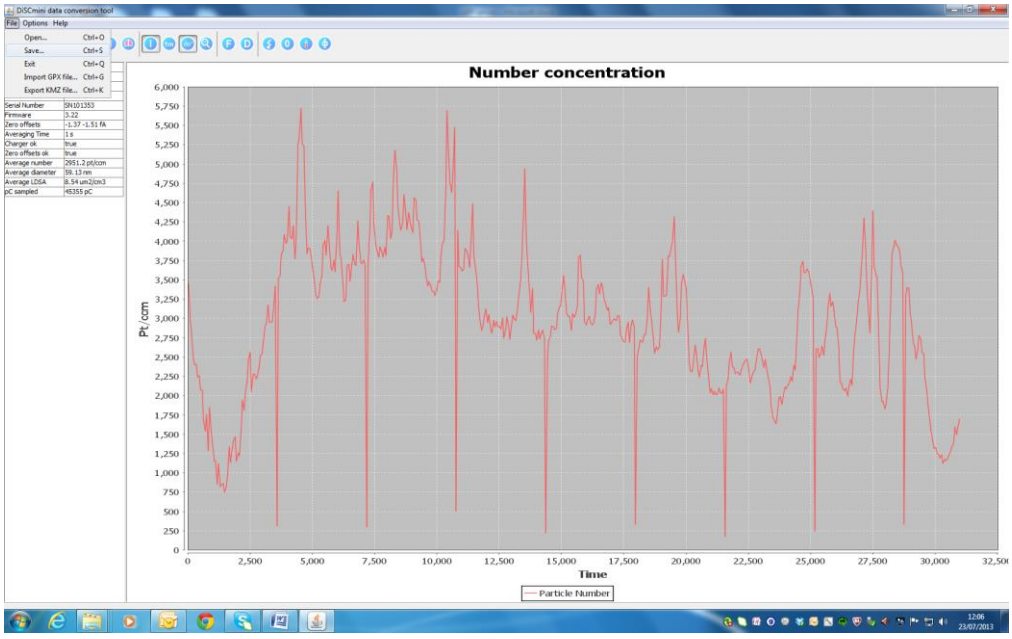


Check behaviour of corona voltage and flowrate during measurement





Save output



8 Documents generated

8.1. Raw datafile

nw PERSONAL AEROSOL MONITOR Data written withSW-Ver 3.22
Filename: 3710M57I.TXT
Averaging Period: 1 sec

Date and Time: 2013.07.10 12:57:36
CalData: SN101353 2.48 29.53 -6.31 1.15 1.0315406.80 0.72
NaCl 2013_03_07
2.48 29.53 -6.31 1.15 1.03 15406.80 0.72
Offsets: -1.37 -1.51
Sampled: 45355 pC C: 52 W: 1

Time	Diffusion	Filter	Temp	Idiff	Ucor	Flow	Batt	Status
0	4.38	12.45	34.8	9.70	3.84	1.00	8.19	8B
1	4.04	12.43	34.8	9.69	3.84	1.00	8.19	8B
2	4.40	12.37	34.8	9.69	3.84	1.00	8.19	8B

8.2. Output datafile

[miniDiSC java tool version 2 output file]
[Data recorded with miniDiSC SN101353 running firmware 3.22]
[File start date: 2013.07.10]
[File start time: 12:57:36]

TimeStamp	Time	Number	Size	LDSA	Filter	Diff
10-Jul-2013 12:58:05	29.5	3446	59.6	10.85	11.02	4.03
10-Jul-2013 12:59:05	89.5	2973	65.2	10.27	10.69	3.57
10-Jul-2013 13:00:05	149.5	2811	66.5	9.91	10.36	3.4
10-Jul-2013 13:01:05	209.5	2479	70.2	9.24	9.77	3.05
10-Jul-2013 13:02:05	269.5	2396	73.2	9.33	9.95	2.99
10-Jul-2013 13:03:05	329.5	2404	71.9	9.19	9.77	2.98
10-Jul-2013 13:04:05	389.5	2243	72.8	8.67	9.24	2.8

9 Support documents and further reading

DISCMINI Manual

HEI Project

Personal and Home Exposure

ID Code								Researcher						
MicroPEM PM2.	Sample (PE / H)	Flow Start	Flow End	Date Start	Time Start	Date End	Time End	Filter Number	Sensor Voltage	PM2.5 reading Start	PM2.5 reading End	COIN CELL Voltage Start	COIN CELL Voltage End	COMMENT #

Micro-Aethalometer	Sample (PE / H)	Flow Start	Flow End	Date Start	Time Start	Date End	Time End	COMMENT #

COMMENTS:Remember to press REC to start logging data Remember to Press REC BEFORE SWITCHING OFF Sensor

UFP Sensor	Sample (PE / H)	Flow Start	Flow End	Date Start	Time Start	Date End	Time End	COMMENT #	Corona Voltage Start	Corona Voltage End	Flowrate Start	Flowrate End	Zero current start	Zero current End

Sampling Sheet for UFP – Tyburn

Site	Tyburn				Researcher		

	Software data							Software data		TSI flowmeter		Dysplay data	
UFP Sensor	Flow Start	Flow End	Date Start	Time Start	Date End	Time End	COMMENT #	Corona Voltage Start	Corona Voltage End	Flowrate Start	Flowrate End	Zero current start	Zero current End

Remember to press REC to start logging data

Remember to Press REC BEFORE SWITCHING OFF Sensor

Downloaded information

File Names	Date Start	Time Start	Date End	Time End	Days operation	COMMENT #

COMMENTS

Filter weighing chart

Researcher		Pre-sampling						Post sampling					
		Date Weighed						Date Weighed					
		Room Temperature			Room RH			Room Temperature			Room RH		
Sample Code		Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight 6	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight 6
Samples													

CORRECTION FACTORS FOR UFP SENSOR

By applying (Fierz et al., 2008) and (Fierz et al., 2011) methods:

1. Calculate what is the maximum concentration (***x***) during the sampling period (e.g. the ID sampling week) measured with the discmini sensor.

x= Maximum UFP measured by the discmini during sampling period.

E= Exponential

2. Apply the validation correction factor corresponding to each discmini to calculate the corrected UFP concentration measured by the discmini. Take into consideration the maximum concentration (x) measured during the sampling period. Each discmini has a different correction factor equation.

$$\boldsymbol{Corrected\ UFP\ concentration} = \frac{\boldsymbol{DM1\ UFP\ concentration}}{\mathbf{7E-6\ x\ +1.4112}}$$

$$\boldsymbol{Corrected\ UFP\ concentration} = \frac{\boldsymbol{DM2\ UFP\ concentration}}{\mathbf{5E-6\ x\ +1.0673}}$$

$$\boldsymbol{Corrected\ UFP\ concentration} = \frac{\boldsymbol{DM3\ UFP\ concentration}}{\mathbf{1E-5\ x\ +1.4727}}$$

CORRECTION FACTORS FOR BC SENSOR

1. Use the Optimised noise-reduction averaging (ONA) algorithm developed by Hagler et al. (2011) to eliminate the noise and negative values from the data (Hagler et al., 2011).

Set up the minimum attenuation (ΔATNmin) to be 0.05

After smoothening the data with the ONA method, **apply the Apte method** to correct the measured BC concentration for parameters such as dark spot and loading effect (Apte et al., 2011).

The Apte correction equation used is:

$BC = BC_0 /(0.88Tr + 0.12)$

Where BC =BC corrected

BC_0 = Instrumented reported BC concentration

Tr = exp(-ATN/100) = aethalometer filter transmission calculated from reported attenuation

0.88 and 0.12 are coefficient values derived in the laboratory.

ONA algorithm can be downloaded from the following page: https://www.epa.gov/air-research/optimized-noise-reduction-algorithm-ona-program-improves-black-carbon-particle

2. Apply the validation correction factor corresponding to each microaethalometer.
Y = Microaethalometer sensor

X = Reference aethalometer

Regression analysis of the microaethalometers against the reference aethalometer in all the ambient sites.

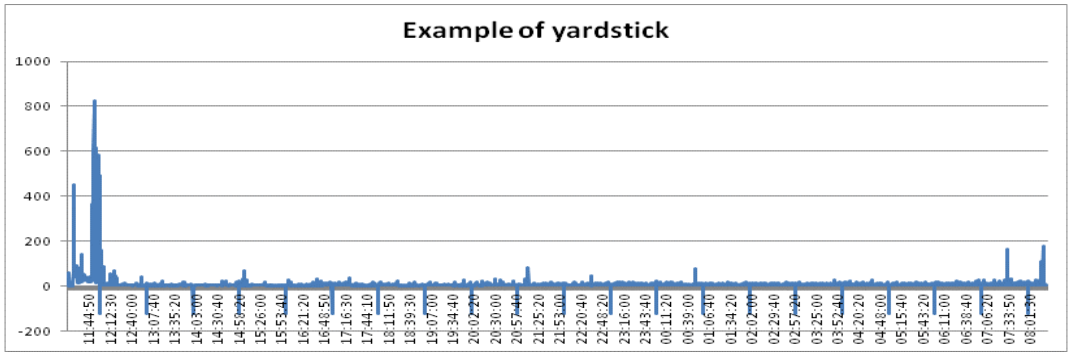
Microaethalometer	Regression coefficients
1	y = 1.0455x
2	y = 0.7890 x
3	y = 0.9318x
4	y = 0.7889x

Hence to correct e.g. readings from sensor 1, you have to apply the following formula to the results of the ONA-Apte concentrations -applied in Steps 1 and 2- to obtain the corrected BC concentration:

$$\text{Sensor 1 BC}_{\text{corrected}}\ (\text{X}) = \frac{\text{BC}_{\text{ONA+Apte}}}{1.0455}$$

CORRECTION FACTORS FOR $PM_{2.5}$ SENSOR

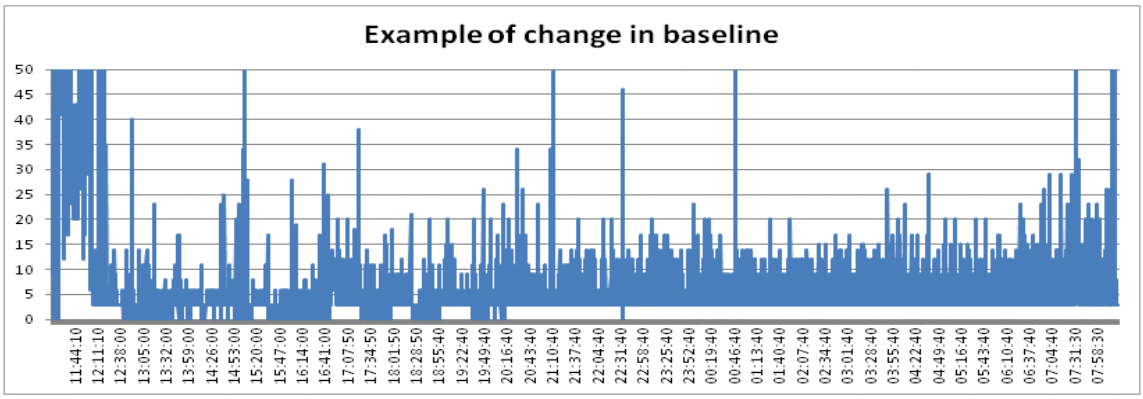
1. Remove the negative yardstick values that will appear at frequent intervals. Each sensor has a different value, but you will recognise the yardstick as they appear at constant periods of time and are always negative. See example below.



In this case, the yardstick is -125 during half of the measurement, and then increases to -122. You should remove these values from the dataset.

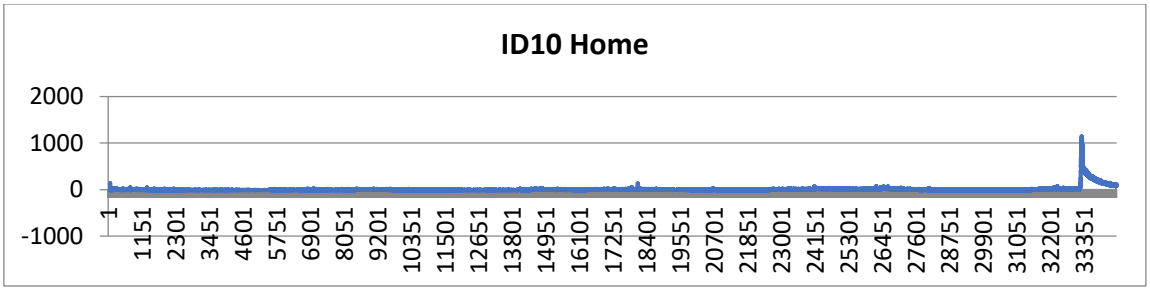
2. Check for baseline consistency. For instance, in the case above, the increase to -122 from the 01/05/2015 at 00:00:00 onwards also indicates that the baseline of the measurement has changed half way through the measurement. In this case all the data points from 01/05/2015 at 00:00:00 need to be corrected. This will imply lowering the readings by 2.8 ug/m3 (the microPEM interval) from the 01/05/2015 at 00:00:00 onwards.
Another indication that the baseline has changed will be when you check the Sampling sheet. When you check the sensor voltage and the $PM_{2.5}$ reading at the start and at the end when the HEPA filter is connected to the microPEM, the end reading would have changed from 0, which was your original reading before the start of the measurement.

You should **highlight with orange** the part of the database that it is affected by the baseline changing.



3. Check for negative baseline values. After you have removed the negative baseline, check the baseline of the measurement. If the values are below 0, you should drag the baseline to nil by adding a value equal to the drop of the baseline. E.g. in Figure below,

identify the more consistent negative $PM_{2.5}$ reading and then correct the baseline by adding that $PM_{2.5}$ value across. If the negative baseline values affect only a part of the reading, apply the correction only to that part. If after adjusting the baseline, there are still some negative values, remove these and mark in red the cells.



4. Check the ratio of the MicroPEM measurements against the gravimetric measurement of the inside filter. After correcting for the baseline, compare the concentrations measured by the sensors with the concentration measured by the inside filter, determined gravimetrically.

5. Calculate a gravimetric correction factor that represents the ratio between the gravimetric concentration and the sensor average concentration.

$$GCF = \frac{Gravimetric\ concentration}{Sensor\ average\ concentration}$$

If the ratio is between 0.7 – 1.3 apply the ratio to the raw data after the baseline has been corrected according to steps 1-3 above.

$$PM2.5\ gravimetrically\ corrected = GCF * Sensor\ reading$$

If the ratio is outside of the range 0.7-1.3, accept the raw data from the sensor after the baseline has been corrected according to steps 1-3 above.

6. Apply the validation correction factor corresponding to each MicroPEM sensor.
Y = MicroPEM sensor

X = Reference $PM_{2.5}$

Regression analysis of the microPEMs against the reference TEOM at Tyburn Nov 2014

MicroPEM	Regression coefficients
1	y = 0.9842x
2	y = 0.9273x
3	y = 1.0293x
4	y = 1.0303x

Hence to correct e.g. readings from sensor 1, you have to apply the following formula to the results of the microPEM sensor refined data –after applying Steps 1 to 4- to obtain the corrected $PM_{2.5}$ concentration:

$$\text{Sensor 1 PM2.5}_{\text{corrected}}\ (\text{X}) = \frac{\text{PM2.5 refined sensor data}}{0.9842}$$

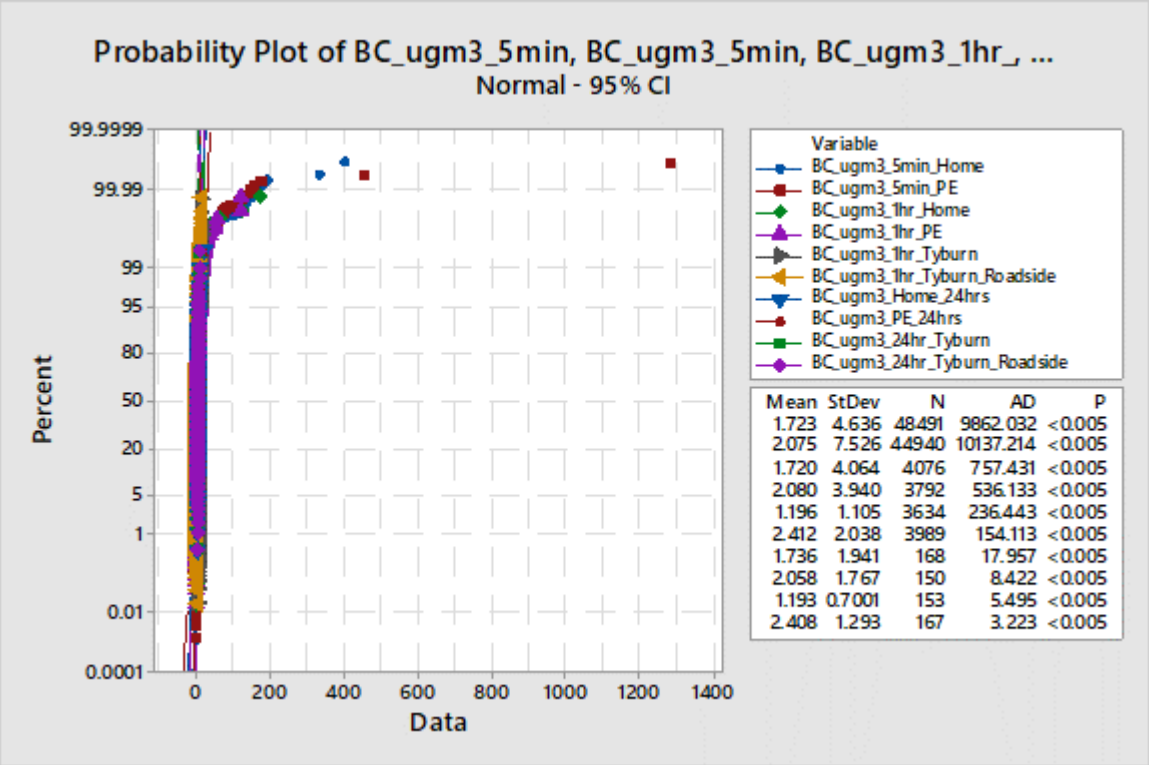
(Delgado-Saborit JM et al., 2017)

Appendix 3

Outputs for chapter 3 results

Black carbon (BC)

Test for normality



A3. Figure 1: Probability Plot for all sites and times intervals measurements for BC

Degree of misclassification

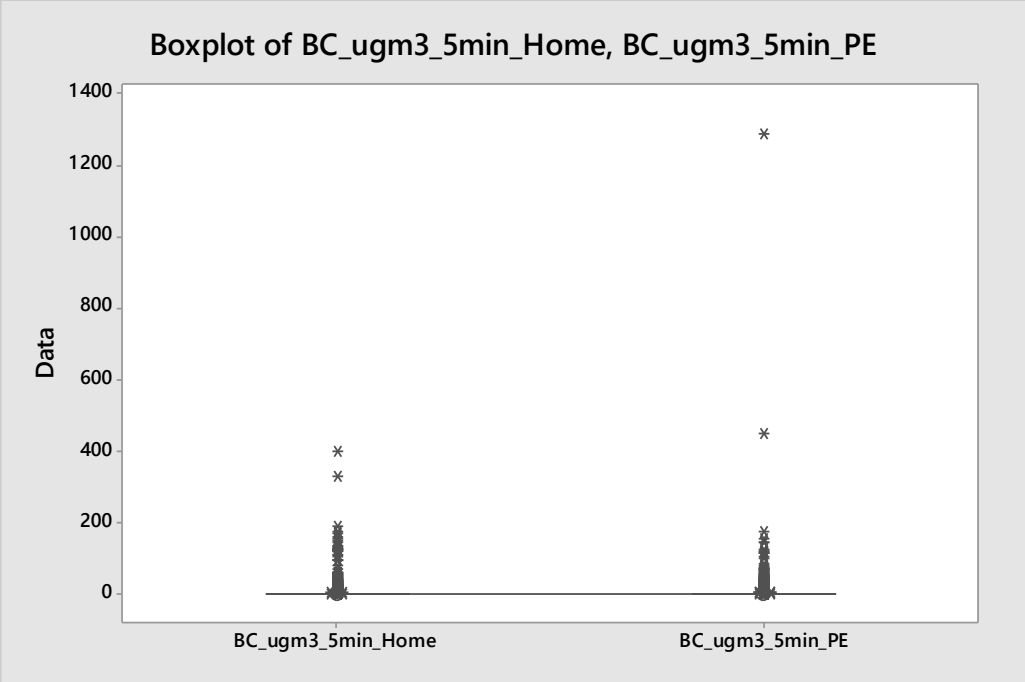
Two-Sample T-Test and CI: BC_ugm3_5min_Home, BC_ugm3_5min_PE

Two-sample T for BC_ugm3_5min_Home vs BC_ugm3_5min_PE

	N	Mean	StDev	SE Mean
BC_ugm3_5min_Home	48491	1.72	4.64	0.021
BC_ugm3_5min_PE	44940	2.08	7.53	0.036

Difference = μ (BC_ugm3_5min_Home) - μ (BC_ugm3_5min_PE)
Estimate for difference: -0.3524
95% CI for difference: (-0.4333, -0.2715)
T-Test of difference = 0 (vs ≠): T-Value = -8.54 P-Value = 0.000 DF = 73657

A3. Figure 2: Two sample t-test output for home and PE sites, at 5 minutes' time interval (BC)



A3. Figure 3: Two sample t-test box plot for home and PE sites, at 5 minutes' time interval (BC)

:

Mann-Whitney Test and CI: BC_ugm3_5min_Home, BC_ugm3_5min_PE

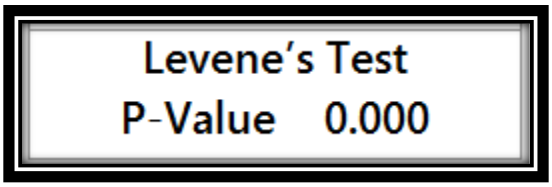
	N	Median
BC_ugm3_5min_Home	48491	1.0631
BC_ugm3_5min_PE	44940	1.1279

Point estimate for η1 - η2 is -0.0590
95.0 Percent CI for η1 - η2 is (-0.0705,-0.0476)
W = 2223544498.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

A3. Figure 4: Mann Whitney test output for home and PE sites, at 5 minutes' time interval (BC)

Test for equal variances:

.



One-way ANOVA: BC_ugm3_1hr_Home, BC_ugm3_1hr_PE, BC_ugm3_1hr_Tyburn, BC_ugm3_1hr_Tyburn_Roads

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were not assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	BC_ugm3_1hr_Home, BC_ugm3_1hr_PE, BC_ugm3_1hr_Tyburn, BC_ugm3_1hr_Tyburn_Roadside

Welch's Test

Source	DF Num	DF Den	F-Value	P-Value
Factor	3	7841.74	387.18	0.000

Model Summary

R-sq	R-sq(adj)	R-sq(pred)
2.05%	2.03%	2.00%

Means

Factor	N	Mean	StDev	95% CI
BC_ugm3_1hr_Home	4076	1.7197	4.0643	(1.5949, 1.8445)
BC_ugm3_1hr_PE	3792	2.0797	3.9404	(1.9543, 2.2052)
BC_ugm3_1hr_Tyburn	3634	1.1958	1.1052	(1.1599, 1.2318)
BC_ugm3_1hr_Tyburn_Roadside	3989	2.4120	2.0380	(2.3487, 2.4753)

A3. Figure 5: ANOVA (equal variance not assumed) output for the sites home, PE, and CS's, at 1- hour time interval (BC)

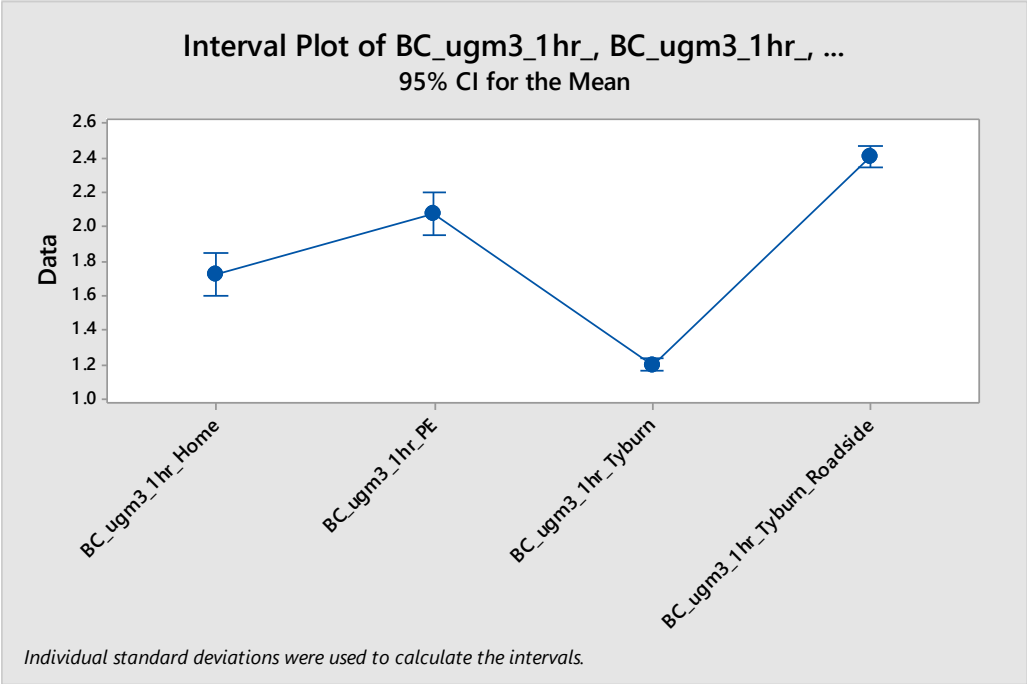
Kruskal-Wallis Test: Reading (1hr) versus Type (1hr)

Kruskal-Wallis Test on Reading (1hr)

Type (1hr)	N	Median	Ave Rank	Z
BC_ugm3_1hr_Home	4076	1.0804	7209.5	-8.92
BC_ugm3_1hr_PE	3792	1.2223	7764.9	0.30
BC_ugm3_1hr_Tyburn	3634	0.9000	6275.3	-22.66
BC_ugm3_1hr_Tyburn_Roadside	3989	1.9000	9616.0	30.65
Overall	15491		7746.0	

H = 1149.21 DF = 3 P = 0.000
H = 1149.37 DF = 3 P = 0.000 (adjusted for ties)

A3. Figure 6: Kruskal-Wallis test output for home, PE, and CS's at 1- hout time interval (BC)



A3. Figure 7: ANOVA (equal variance not assumed) plot for the sites home, PE, and CS's, at 1 hours' time interval (BC)

Test for equal variances

Levene's Test	
P-Value	0.000

One-way ANOVA: BC_ugm3_Home_24h, BC_ugm3_PE_24hrs, BC_ugm3_24hr_Tyb, BC_ugm3_24hr_Tyb

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were not assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	BC_ugm3_Home_24hrs, BC_ugm3_PE_24hrs, BC_ugm3_24hr_Tyburn, BC_ugm3_24hr_Tyburn_Roadside

Welch's Test

Source	DF Num	DF Den	F-Value	P-Value
Factor	3	326.710	42.22	0.000

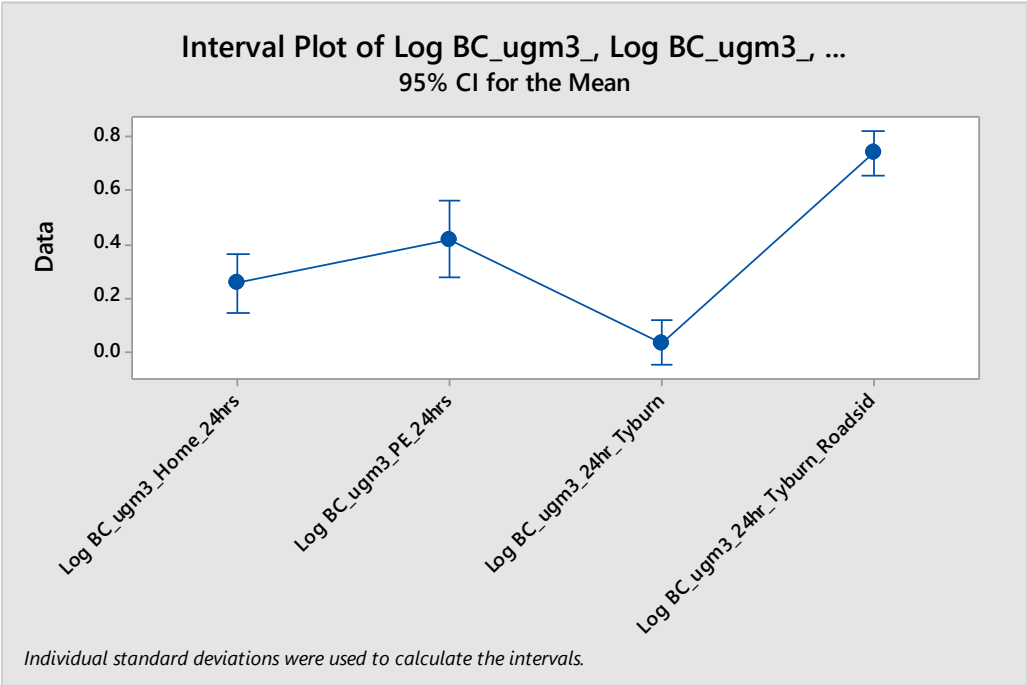
Model Summary

R-sq	R-sq(adj)	R-sq(pred)
8.06%	7.62%	6.90%

Means

Factor	N	Mean	StDev	95% CI
BC_ugm3_Home_24hrs	168	1.736	1.941	(1.440, 2.032)
BC_ugm3_PE_24hrs	150	2.058	1.767	(1.773, 2.343)
BC_ugm3_24hr_Tyburn	153	1.1930	0.7001	(1.0811, 1.3048)
BC_ugm3_24hr_Tyburn_Roadside	167	2.408	1.293	(2.211, 2.606)

A3. Figure 6: ANOVA (equal variance not assumed) output for the sites home, PE, and CS's, at 24 hours' time interval (BC)



A3. Figure 7: ANOVA (equal variance not assumed) plot for the sites home, PE, and CS's, at 24 hours' time interval (BC)

Kruskal-Wallis Test: Reading (24hr) versus Type (24hr)

Kruskal-Wallis Test on Reading (24hr)

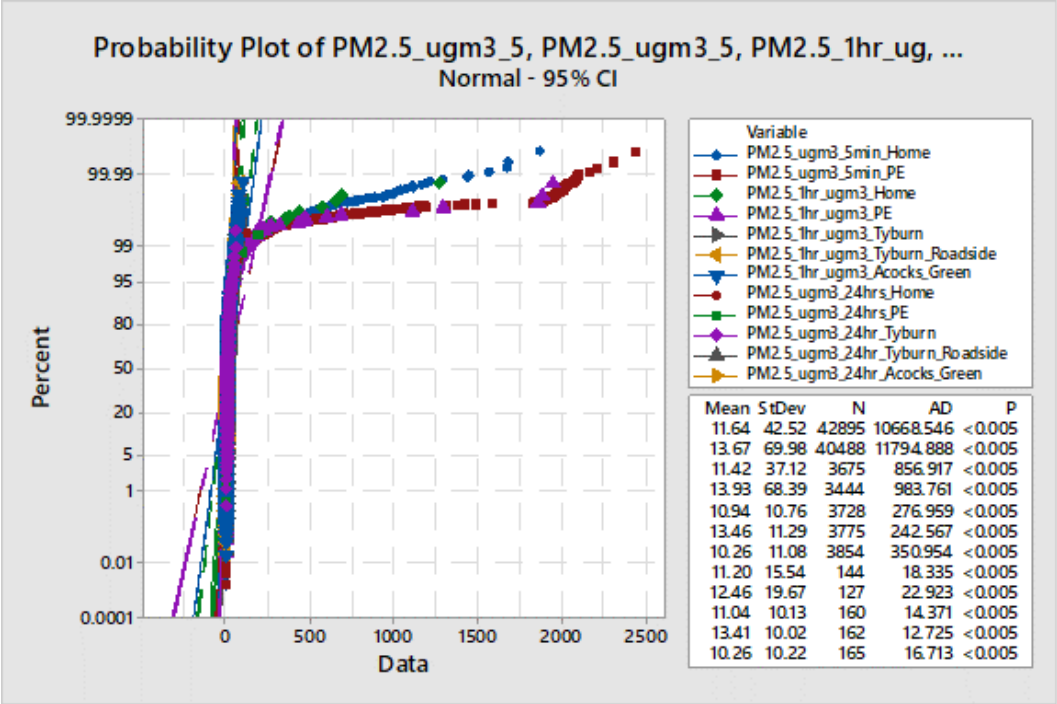
Type (24hr)	N	Median	Ave Rank	Z
BC_ugm3_24hr_Tyburn	153	1.022	221.7	-7.52
BC_ugm3_24hr_Tyburn_Roadside	167	2.096	426.2	8.71
BC_ugm3_Home_24hrs	168	1.277	285.5	-2.79
BC_ugm3_PE_24hrs	150	1.543	338.6	1.45
Overall	638		319.5	

H = 106.33 DF = 3 P = 0.000
H = 106.33 DF = 3 P = 0.000 (adjusted for ties)

A3. Figure 8: Kruskal-Wallis test output for home, PE, and CS's at 24 hours' time interval (BC)

Particulate matter ($PM_{2.5}$)

Test for normality



A3. Figure 9: Probability Plot of all sites and times intervals measurements for $PM_{2.5}$

Degree of misclassification

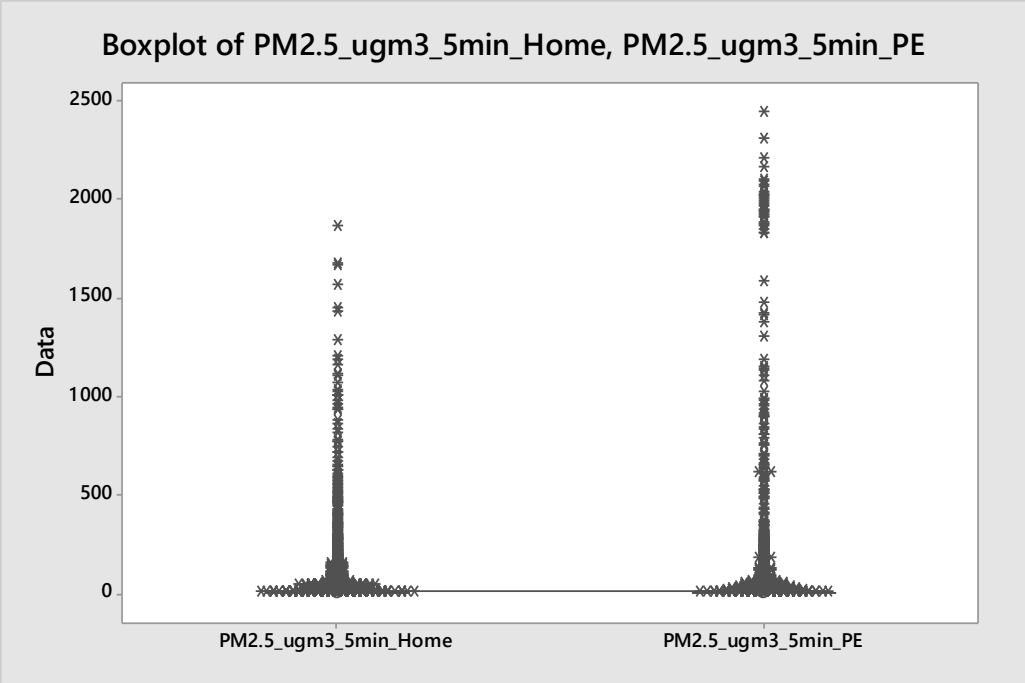
Two-Sample T-Test and CI: PM2.5_ugm3_5min_Home, PM2.5_ugm3_5min_PE

```
Two-sample T for PM2.5_ugm3_5min_Home vs PM2.5_ugm3_5min_PE

                          N  Mean  StDev  SE Mean
PM2.5_ugm3_5min_Home  42895  11.6   42.5     0.21
PM2.5_ugm3_5min_PE    40488  13.7   70.0     0.35


Difference = μ (PM2.5_ugm3_5min_Home) - μ (PM2.5_ugm3_5min_PE)
Estimate for difference:  -2.023
95% CI for difference:  (-2.815, -1.232)
T-Test of difference = 0 (vs ≠): T-Value = -5.01  P-Value = 0.000  DF = 66055
```

A3. Figure 10: Two sample t-test output for home and PE, at 5 minutes' time interval ($PM_{2.5}$)



A3. Figure 11: Two sample t-test box plot for home and PE sites, at 5 minutes' time interval ($PM_{2.5}$)

Mann-Whitney Test and CI: PM2.5_ugm3_5min_Home, PM2.5_ugm3_5min_PE

	N	Median
PM2.5_ugm3_5min_Home	42895	4.590
PM2.5_ugm3_5min_PE	40488	6.060

Point estimate for η1 - η2 is -1.150
95.0 Percent CI for η1 - η2 is (-1.200,-1.089)
W = 1642726002.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

A3. Figure 12: Mann Whitney test output for home and PE, at 5 minutes' time intervals ($PM_{2.5}$)

Test for equal variances

Levene's Test	
P-Value	0.000

One-way ANOVA: PM2.5_1hr_ug, PM2.5_1hr_ug, PM2.5_1hr_ug, PM2.5_1hr_ug, PM2.5_1hr_ug

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were not assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	PM2.5_1hr_ugm3_Home, PM2.5_1hr_ugm3_PE, PM2.5_1hr_ugm3_Tyburn, PM2.5_1hr_ugm3_Tyburn_Roadside, PM2.5_1hr_ugm3_Acocks_Green

Welch's Test

Source	DF Num	DF Den	F-Value	P-Value
Factor	4	8807.08	44.11	0.000

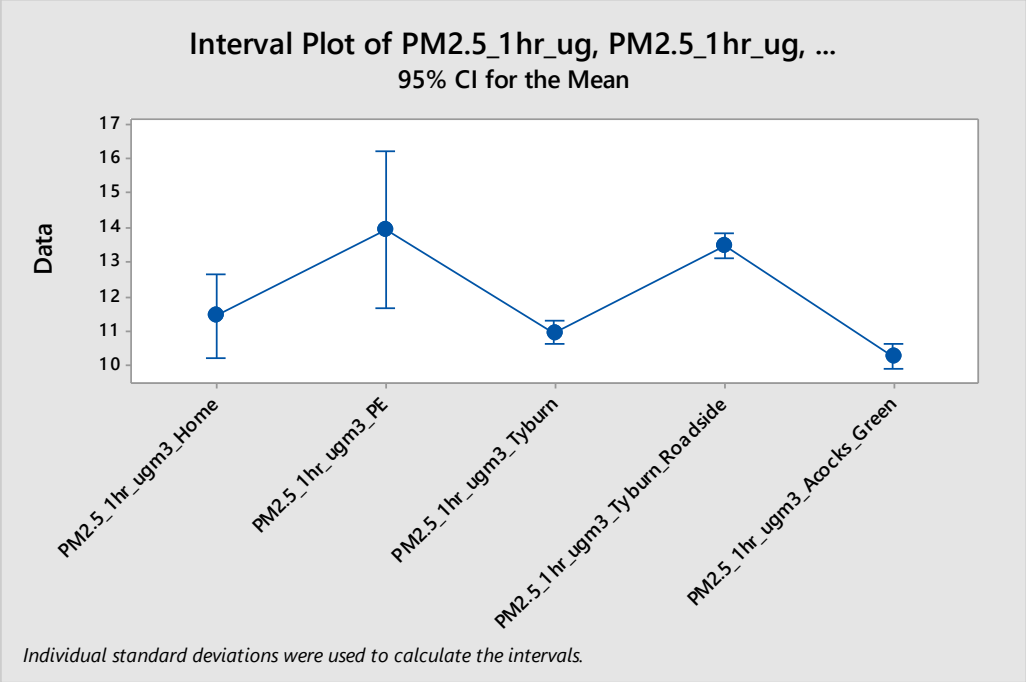
Model Summary

R-sq	R-sq(adj)	R-sq(pred)
0.17%	0.15%	0.11%

Means

Factor	N	Mean	StDev	95% CI
PM2.5_1hr_ugm3_Home	3675	11.421	37.124	(10.220, 12.622)
PM2.5_1hr_ugm3_PE	3444	13.93	68.39	(11.64, 16.21)
PM2.5_1hr_ugm3_Tyburn	3728	10.944	10.755	(10.599, 11.290)
PM2.5_1hr_ugm3_Tyburn_Roadside	3775	13.459	11.293	(13.099, 13.820)
PM2.5_1hr_ugm3_Acocks_Green	3854	10.256	11.079	(9.906, 10.606)

A3. Figure 13: ANOVA (equal variance not assumed) output for home, PE, and CS's, at 1-hour time interval (PM2.5)



A3. Figure 14: ANOVA (equal variance not assumed) plot for home, PE, and CS's, at 1-hour time interval ($PM_{2.5}$)

Kruskal-Wallis Test: Reading (1hr) versus Type (1hr)

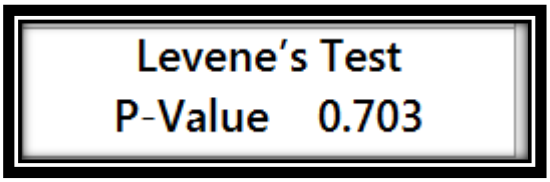
Kruskal-Wallis Test on Reading (1hr)

Type (1hr)	N	Median	Ave Rank	Z
PM2.5_1hr_ugm3_Acocks_Green	3854	6.600	8995.4	-3.18
PM2.5_1hr_ugm3_Home	3675	4.620	7019.2	-28.18
PM2.5_1hr_ugm3_PE	3444	6.330	8636.0	-7.35
PM2.5_1hr_ugm3_Tyburn	3728	7.600	9755.5	6.62
PM2.5_1hr_ugm3_Tyburn_Roadside	3775	10.000	11686.3	31.61
Overall	18476		9238.5	

H = 1518.32 DF = 4 P = 0.000
H = 1518.33 DF = 4 P = 0.000 (adjusted for ties)

A3. Figure 15: Kruskal-Wallis test output for home, PE, and CS's, at 1-hour time interval ($PM_{2.5}$)

Test for equal variances:



One-way ANOVA: PM2.5_ugm3_2, PM2.5_ugm3_2, PM2.5_ugm3_2, PM2.5_ugm3_2, PM2.5_ugm3_2

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	PM2.5_ugm3_24hrs_Home, PM2.5_ugm3_24hrs_PE, PM2.5_ugm3_24hr_Tyburn, PM2.5_ugm3_24hr_Tyburn_Roadside, PM2.5_ugm3_24hr_Acocks_Green

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	988	247.0	1.40	0.232
Error	753	132904	176.5		
Total	757	133892			

Model Summary

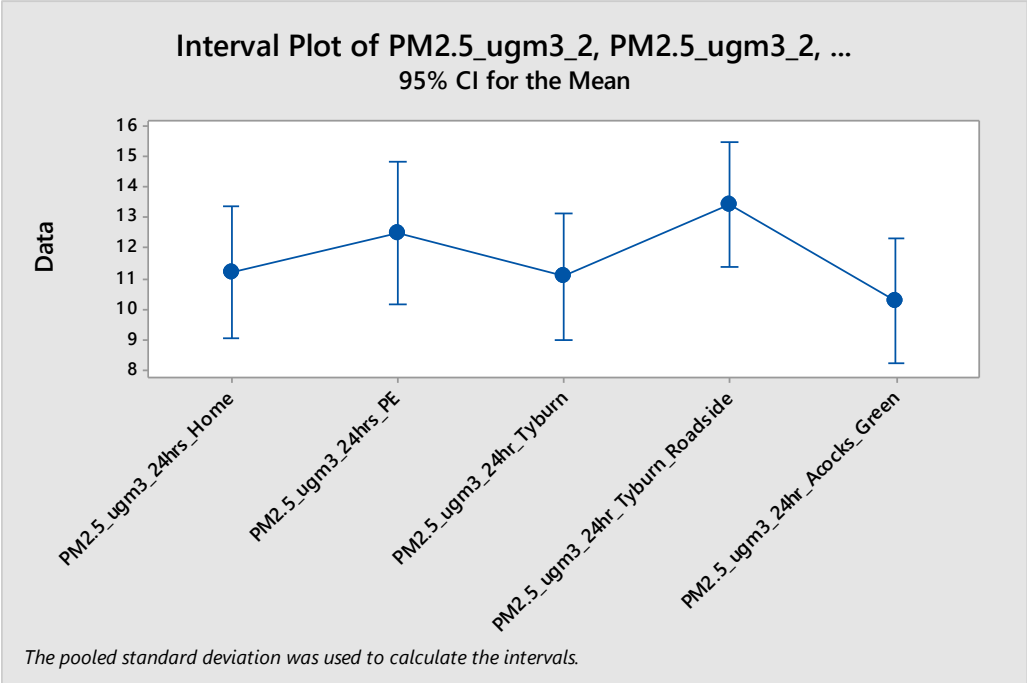
S	R-sq	R-sq(adj)	R-sq(pred)
13.2853	0.74%	0.21%	0.00%

Means

Factor	N	Mean	StDev	95% CI
PM2.5_ugm3_24hrs_Home	144	11.20	15.54	(9.02, 13.37)
PM2.5_ugm3_24hrs_PE	127	12.46	19.67	(10.15, 14.78)
PM2.5_ugm3_24hr_Tyburn	160	11.044	10.131	(8.982, 13.106)
PM2.5_ugm3_24hr_Tyburn_Roadside	162	13.405	10.019	(11.356, 15.455)
PM2.5_ugm3_24hr_Acocks_Green	165	10.265	10.220	(8.234, 12.295)

Pooled StDev = 13.2853

A3. Figure 16: ANOVA (equal variance assumed) output for home, PE, and CS's, at 24 hours' time interval (PM2.5)



A3. Figure 17: ANOVA (equal variance assumed) plot for home, PE, and CS's, at 24 hours' time interval (PM2.5)

Kruskal-Wallis Test: Reading (24hr) versus Type (24hr)

Kruskal-Wallis Test on Reading (24hr)

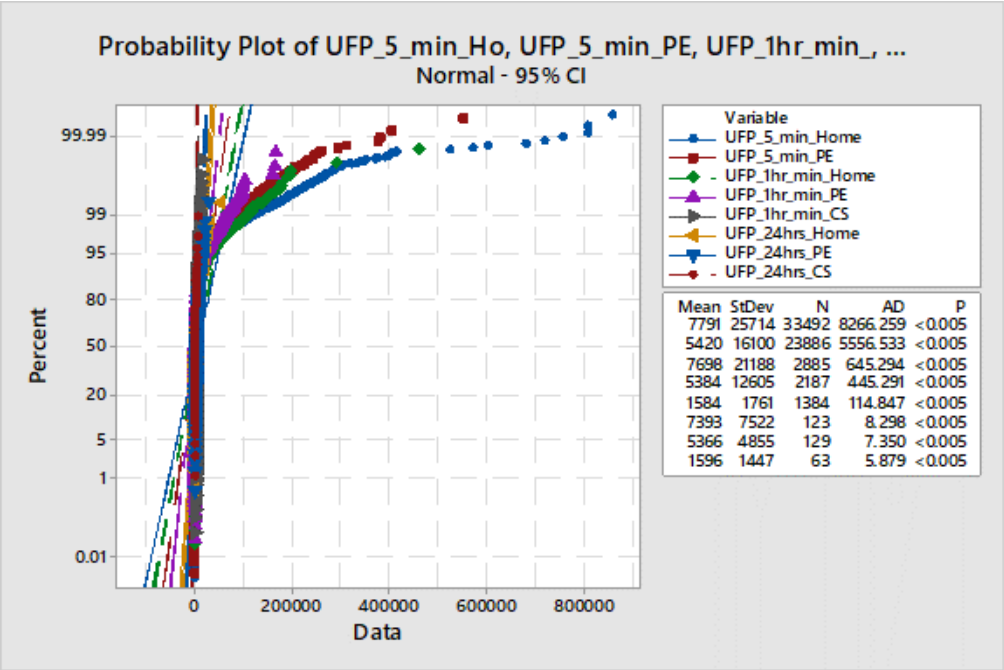
Type (24hr)	N	Median	Ave Rank	Z
PM2.5_ugm3_24hr_Acocks_Green	165	7.075	336.8	-2.83
PM2.5_ugm3_24hr_Tyburn	160	7.969	375.0	-0.29
PM2.5_ugm3_24hr_Tyburn_Roadside	162	10.491	472.6	6.10
PM2.5_ugm3_24hrs_Home	144	5.985	311.3	-4.16
PM2.5_ugm3_24hrs_PE	127	8.335	399.3	1.12
Overall	758		379.5	

H = 50.67 DF = 4 P = 0.000
H = 50.67 DF = 4 P = 0.000 (adjusted for ties)

A3. Figure 18: Kruskal-Wallis test output for home, PE, and CS's, at 24 hours' time interval ($PM_{2.5}$)

Ultrafine particles (UFP)

Test for normality



A3. Figure 19: Probability Plot of all sites and times intervals measurements for UFP

Degree of misclassification

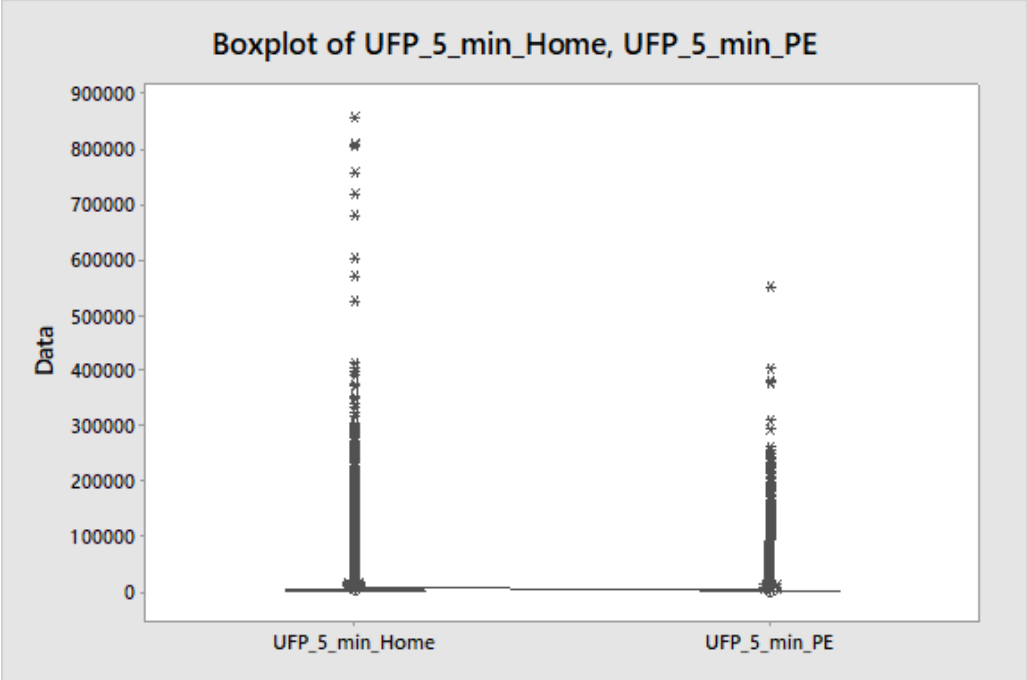
Two-Sample T-Test and CI: UFP_5_min_Home, UFP_5_min_PE

```
Two-sample T for UFP_5_min_Home vs UFP_5_min_PE

                    N  Mean  StDev  SE Mean
UFP_5_min_Home  33492  7791  25714      141
UFP_5_min_PE    23886  5420  16100      104


Difference = μ (UFP_5_min_Home) - μ (UFP_5_min_PE)
Estimate for difference:  2371
95% CI for difference:  (2028, 2714)
T-Test of difference = 0 (vs ≠): T-Value = 13.56  P-Value = 0.000  DF = 56494
```

A3. Figure 20: Two sample t-test output for home and PE, at 5 minutes' time interval (UFP)



A3. Figure 21: Two sample t-test box plot for home and PE sites, at 5 minutes' time interval (UFP)

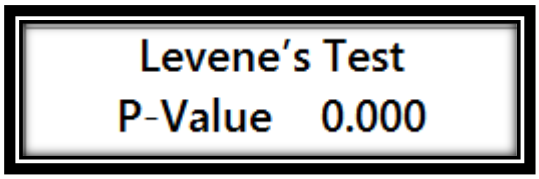
Mann-Whitney Test and CI: UFP_5_min_Home, UFP_5_min_PE

	N	Median
UFP_5_min_Home	33492	2035.0
UFP_5_min_PE	23886	1839.6

Point estimate for η1 - η2 is 229.7
95.0 Percent CI for η1 - η2 is (202.4,256.9)
W = 993370932.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

A3. Figure 22: Mann Whitney Test output for home and PE, at 5 minutes time interval (UFP)

Test for equal variances:



One-way ANOVA: UFP_1hr_min_Home, UFP_1hr_min_PE, UFP_1hr_min_CS

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were not assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	3	UFP_1hr_min_Home, UFP_1hr_min_PE, UFP_1hr_min_CS

Welch's Test

Source	DF Num	DF Den	F-Value	P-Value
Factor	2	3465.55	210.49	0.000

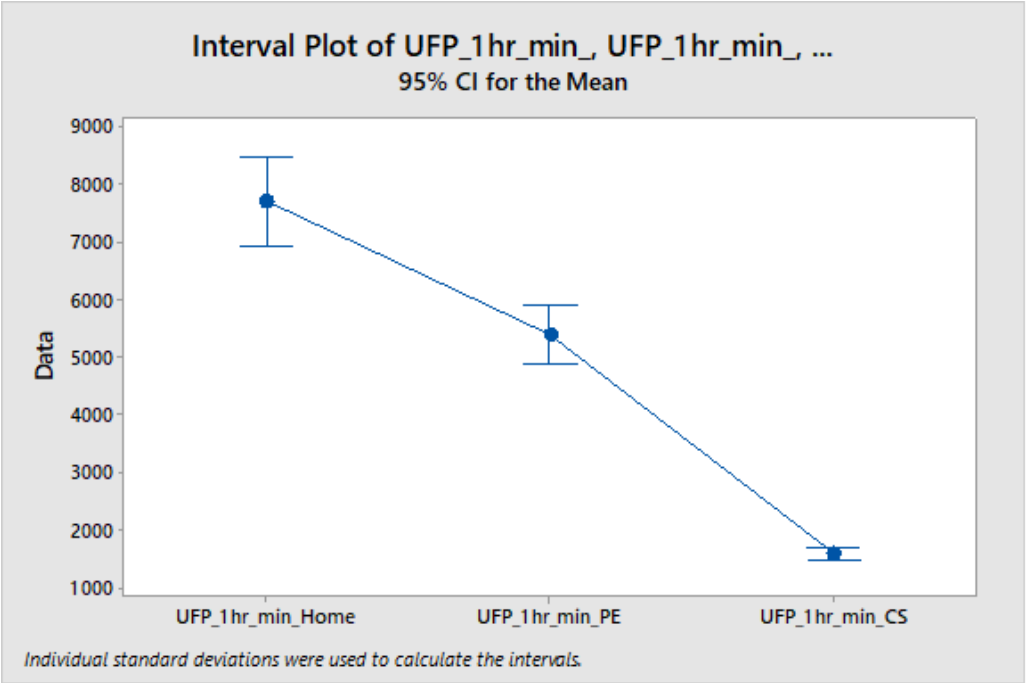
Model Summary

R-sq	R-sq(adj)	R-sq(pred)
2.09%	2.06%	2.02%

Means

Factor	N	Mean	StDev	95% CI
UFP_1hr_min_Home	2885	7698	21188	(6925, 8472)
UFP_1hr_min_PE	2187	5384	12605	(4855, 5912)
UFP_1hr_min_CS	1384	1583.7	1760.6	(1490.9, 1676.5)

A3. Figure 23: ANOVA (equal variance not assumed) output for home, PE, and CS, at 1-hour time interval (UFP)



A3. Figure 24: ANOVA (equal variance not assumed) plot for home, PE, and CS, at 1-hour time interval (UFP)

Kruskal-Wallis Test: Reading (1hr) versus Type (1hr)

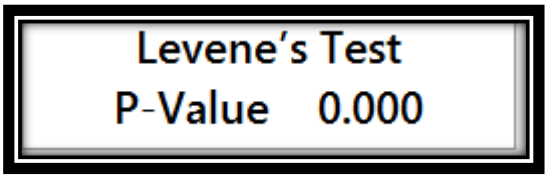
Kruskal-Wallis Test on Reading (1hr)

Type (1hr)	N	Median	Ave Rank	Z
UFP_1hr_min_CS	1384	930.5	2218.2	-22.75
UFP_1hr_min_Home	2885	2081.0	3583.5	13.75
UFP_1hr_min_PE	2187	1965.0	3399.6	5.28
Overall	6456		3228.5	

H = 529.69 DF = 2 P = 0.000
H = 529.69 DF = 2 P = 0.000 (adjusted for ties)

A3. Figure 25: Kruskal-Wallis test output at home, PE, and CS, at 1-hour time interval (UFP)

Test for equal variances:



One-way ANOVA: UFP_24hrs_Home, UFP_24hrs_PE, UFP_24hrs_CS

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were not assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	3	UFP_24hrs_Home, UFP_24hrs_PE, UFP_24hrs_CS

Welch's Test

Source	DF Num	DF Den	F-Value	P-Value
Factor	2	195.333	60.57	0.000

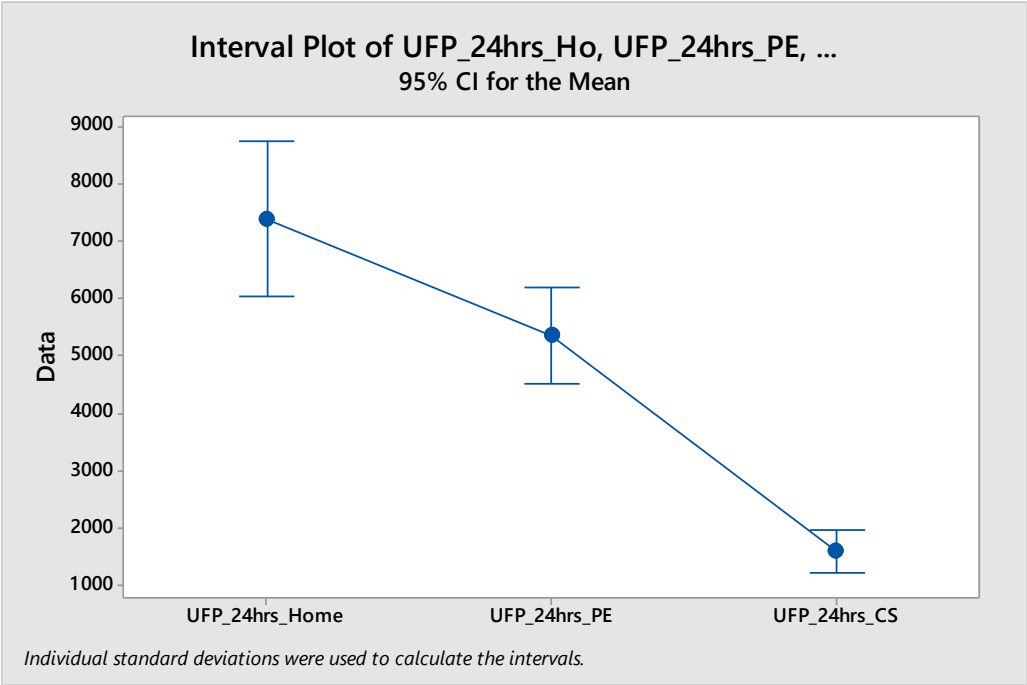
Model Summary

R-sq	R-sq(adj)	R-sq(pred)
12.23%	11.67%	10.79%

Means

Factor	N	Mean	StDev	95% CI
UFP_24hrs_Home	123	7393	7522	(6050, 8736)
UFP_24hrs_PE	129	5366	4855	(4520, 6211)
UFP_24hrs_CS	63	1596	1447	(1231, 1960)

A3. Figure 26: ANOVA (equal variance not assumed) output for home, PE, and CS, at 24 hours' time interval (UFP)



A3. Figure 27: ANOVA (equal variance not assumed) plot for home, PE, and CS, at 24 hours' time interval (UFP)

Kruskal-Wallis Test: Reading (24hr) versus Type (24hr)

Kruskal-Wallis Test on Reading (24hr)

Type (24hr)	N	Median	Ave Rank	Z
UFP_24hrs_CS	63	911.2	66.9	-8.88
UFP_24hrs_Home	123	4443.5	192.2	5.34
UFP_24hrs_PE	129	3802.5	169.9	1.92
Overall	315		158.0	

H = 82.64 DF = 2 P = 0.000

A3. Figure 28: Kruskal-Wallis test output for home, PE and CS, at 24 hours' time interval (UFP)

Appendix 4

Characterization of the profile of the pollutant mixture associated with activities conducted and microenvironments visited by subjects

A4. Table 1: Detailed activities and their codes

ACTIVITY CODE	AGGREGATED Activity of interest	DETAILED CODE Activities	DETAILED GROUP Activities	DETAILED Activities
1	Travelling in vehicle	10	Travelling in vehicle	Commuting Driving
2	Outdoors Commuting – Walking, running	21	Commuting outdoors	Cycling Walking/commuting Collecting car Walking Walking and running Walking dog
		22	Waiting for train/bus	Waiting bus Waiting for train Waiting train
3	Other outdoor activities (e.g. in a park)	31	Exercising outdoors	Exercising (IF OUTDOORS) Running Playing Playing football Playing golf Playing in garden
		32	Buying/shopping	Buy dinner (IF OUTDOORS) Buying coffee (IF OUTDOORS) Buying food (IF OUTDOORS) Buying snack (IF OUTDOORS) Shopping (IF OUTDOORS)
		33	Gardening	Checking garden Gardening In the garden Watering plants
		34	Relaxing outdoors	Sitting Sitting outside Sitting with friends (IF OUTDOORS) Standing Standing outside Waiting outdoor
		35	Other outdoor activities	Coal fire BBQ Playing with kids

ACTIVITY CODE	AGGREGATED Activity of interest	DETAILED CODE Activities	DETAILED GROUP Activities	DETAILED Activities
4	Working	40		Browsing Cognitive test Collecting essay Eating/working Emailing Exam Examination Experiment part Demonstrating lab Filming Homework Hand in work Having lecture Lecture Looking for books Office Painting Preparing film Preparing for class Preparing sensors Revising Seminar Setting up equipment Studying Studying/Candle burning Studying/relaxing Taking exam Taking test Teaching Tutoring Tutor meeting Using computer Using computer/painting and filing nails Using PC Working Working/Eating Working on laptop Working online Writing

ACTIVITY CODE	AGGREGATED Activity of interest	DETAILED CODE Activities	DETAILED GROUP Activities	DETAILED Activities
5	Indoor activities – light exercise (e.g. relaxing)	51	Ablutions / Getting ready	Bathing Bathing child Bathroom Brushing teeth Brushing teeth/Washing Changing clothes Dressing Dressing up Drying hair Getting dressed Getting ready Getting up Getting up/checking e-mails Going to the bathroom and praying Hair cuts Hair done Showering Showering/resting Showering/studying Toilet
		52	Food related	Dinner Drinking Drinking coffee Drinking tea Eating Eating/reading/Watching movie with friends Eating/Relaxing Eating/resting Eating/Sitting Eating/Studying Eating/TV Eating/washing dishes Eating/watching tv Eating/Talking to friend Feeding animals Having coffee Lunch break Ordering drink Ordering food Nap/eating
		53	Indoor leisure Playing, reading, TV	Back home Borrowing books Playing games Playing piano Playing video games PlayStation T.V T.V/Eating Reading

				Reading/watching movie Reading/watching T.V Resting/working Sitting Sitting/brought package Standing inside Taking break Playing with kids/children Playing with children Playing with children/ watching tv Playing with kids Playing games Watching movie Watching T. V
		54	Socializing	Sitting with friends (IF INDOORS) Having guests Meeting Meeting friend Partying Sitting with friends Socializing Socializing/T. V Talking to friend Visiting Visiting father Visiting friend Using phone Phone call Waiting for friend
		55	Doctor related	Doctor appointment Doctor examination Medical check up
		56	Sensors related	Charging sensors Sampling(Ada) Sensors at home Sensors at home charging/subject went out Sensors left at office/subject in lab Sensors charging Sensors off Start sampling Testing
		57	Others	Arriving home Having choir Having break Meter reading Packing Packing up Preparing stuff Reaching home Shopping Standing bank Tire fixing

				Waiting Walking/eating/resting

ACTIVITY CODE	AGGREGATED Activity of interest	DETAILED CODE Activities	DETAILED GROUP Activities	DETAILED Activities
6	Indoor activities – medium exercise (e.g. housework)	61	Cleaning / House chores / Family activities	Cleaning Cleaning cooker Cleaning equipment Home chores House chores Hoovering Ironing Laundry Laundry/washing dishes Tidying Tidying/resting Using computer/cleaning shoes Using computer/folding clothes Vacuuming Vacuuming/cleaning Washing Washing dishes Washing up Waste disposing With baby
7	Indoor activities – High exercise	71	Exercising	Dancing Exercising Practicing Swimming Training Working out Yoga Yoga sweat
		72	Other House chores	Changing carpet Moving boxes Moving furniture

ACTIVITY CODE	AGGREGATED Activity of interest	DETAILED CODE Activities	DETAILED GROUP Activities	DETAILED Activities
8	Indoor activities – cooking	81	Unspecific cooking	Baking Baking/ eating Cleaning/cooking Cooking and baking Cooking and washing dishes Cooking/Eating Cooking/eating/chatting Cooking/eating/resting Cooking/Eating/Watching T.V Cooking/T. V Heating food/eating Light cooking Making breakfast Making tea Prepare baby's food Prepare breakfast Prepare Dinner Preparing breakfast Preparing food Preparing food/eating Preparing lunch Preparing lunch/eating Preparing meal/Eating
		82	Someone else cooking	Flat mate cooking Housemate cooking Husband cooking Landlord cooking/washing up Mom cooking
		83	Reheating, microwaving, drinks	Re-heat foods/cooking Reheating food Microwaving Microwaving/Eating Making and drinking tea Making coffee Making coffee/drinking Making drink Making drink/resting

ACTIVITY CODE	AGGREGATED Activity of interest	DETAILED CODE Activities	DETAILED GROUP Activities	DETAILED Activities
9	Indoor activities - rest (i.e. Sleeping, relaxing)	91	Relaxing	Incense burning Lighting candles Lighting incense Praying Laying Relaxing Relaxing/showering Resting Resting all day/was ill Resting/eating Waking up
		92	Sleeping	Prepare for sleep Bath & Sleep Napping Sleeping Sleeping/toilet Somebody smoked in the living room/sleeping Put children to sleep Woke up/getting ready Woke up

A4. Table 2: Detailed microenvironments and their codes

CODE	microenvironments of interest	microenvironments
1	Indoors – Home	Bathroom Bathroom and living room Bathroom/bedroom Bedroom Bedroom/living room Downstairs Front room Hall Hallway Home Living room Lounge Sensors at home charging/subject went out
2	Indoors – friends/relative's homes	Care home Friend home Friend house Girlfriend house Parents home (P/home)
3	Indoors – Kitchen	Kitchen Kitchen/Lounge

4	Indoors – Office	Arts building Arts floor3 Arts floor4 Arts floor5 Arts floors6 Arts/Campus Ashely building Aston webb Bank Bank/University Guild Campus Car agency Class Classroom College GEES building Geography building Indoors (working) Lab Law school Learning Centre Lecture Mechanical engineering building Office Physics building Research Centre School hall University Uni/office University campus University house University/pharmacy building Work Work place
CODE	**microenvironments of interest**	**microenvironments**
5	Indoors – hospitality retailers (pubs, restaurants)	Bar Café Canteen/QE hospital Canteen Coffee shop Costa Costa University Hair dresser Indoor

		Pub Restaurant Sandwich shop Selly oak (Eating) Staff house Sunrise (care house) University-indoors
6	Indoors – others	Church Hotel University Bramall
7	Indoors – shopping areas (supermarket, shops, shopping centres)	Aldi Argos Bullring Halfords Homebase Indoors (shopping) Matalan Sainsbury Shop Shopping Centre Stationary store Store Supermarket Tesco Tesco/new street Town Centre (shopping) Venture bikes
8	In vehicles (bus, car, train)	Bus Car Train
9	Outdoors – traffic areas	Bristol rd. Bus station Bus stop Car park Hagley rd. New street station New street station platform Road Street Train station /train st University station

CODE	microenvironments of interest	microenvironments
10	Outdoors – non-traffic areas	Campus/street City Centre Disposal Garage Garden Golf field In and out building Outside Outdoor Outside university Park Road/University Street Street/campus To city Centre To Uni train st Town University-outdoors University square University/ to office
11	Hospital / Medical related	City hospital Dentist Doctor room Hospital ward Medical Centre Medical Centre lobby Medical Centre reception Pharmacy
12	Indoors Exercising	Athlete box (gym) Dance class Fitness class Gym Mosely baths Sport Centre Swimming pool Yoga/ Yoga sweat class

A4. Table 3: Personal exposures to BC (µg/m³) concentrations associated with activities at 5 minutes' time interval

		Travelling in vehicle	Outdoors commuting _ Walking, running	Other outdoor activities	Working	Indoor activities _ Light exercise	Indoor activities _ Medium exercise	Indoor activities _ High exercise	Indoor activities - Cooking	Indoor activities - Rest
N	Valid	1362	1702	563	10142	8697	463	376	1840	19795
	Missing	18433	18093	19232	9653	11098	19332	19419	17955	0
Mean		5.2	3.6	4.0	1.7	2.2	2.6	2.4	2.9	1.7
Std. Deviation		13.5	8.3	8.1	3.6	14.1	3.4	3.5	5.9	3.1
Minimum		0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Maximum		452.9	145.8	147.7	175.3	1284.2	41.6	29.0	115.6	87.7
Percentiles	25	1.1	0.9	1.3	0.5	0.6	0.7	0.9	0.7	0.5
	50	2.6	1.7	2.1	1.0	1.3	1.6	1.3	1.6	1.0
	75	6.6	3.7	4.1	1.9	2.4	3.0	2.2	2.9	2.0
Skewness		27.0	10.8	11.5	27.3	87.4	5.0	4.3	9.1	10.0

A4. Table 4: Personal exposures to BC (µg/m³) concentrations associated with microenvironments at 5 minuets' time interval

		Indoors - Home	Indoors - friends/ relative's homes	Indoors - Kitchen	Indoors - Office	Indoors - hospitality retailers	Indoors - others	Indoors - shopping areas	In vehicles	Outdoors - traffic areas	Outdoors - non-traffic areas	Hospital / Medical related	Indoors exercising
N	Valid	31346	473	1668	6373	650	91	313	1375	1382	870	100	297
	Missing	0	30873	29678	24973	30696	31255	31033	29971	29964	30476	31246	31049
Mean		1.8	1.4	2.7	1.6	3.5	1.9	2.9	5.2	4.0	3.4	2.2	3.2
Std. Deviation		7.8	1.2	5.0	4.2	6.0	1.9	2.5	13.5	8.9	6.8	2.6	4.0
Minimum		0.0	0.2	0.1	0.0	0.1	0.2	0.1	0.0	0.1	0.0	0.2	0.4
Maximum		1284.2	11.4	77.5	175.3	74.6	6.4	14.4	452.9	145.8	147.7	15.1	29.0
Percentiles	25.0	0.5	0.4	1.0	0.5	0.9	0.5	1.1	1.1	0.9	1.1	0.6	1.0
	50.0	1.0	0.9	1.7	1.0	1.8	0.6	2.1	2.6	1.9	1.8	1.2	1.5
	75.0	2.1	2.3	2.7	1.8	3.3	4.0	3.8	6.6	4.1	3.6	2.8	4.8
Skewness		139.8	1.8	8.8	27.0	6.1	0.9	1.8	26.6	10.3	12.9	3.0	3.2

A4. Table 5: Personal exposure to $PM_{2.5}$ (µg/m³) concentrations associated with activities at 5 minutes' time interval

		Travelling in vehicle	Outdoors commuting - Walking, running	Other outdoor activities	Working	Indoor activities - Light exercise	Indoor activities - Medium exercise	Indoor activities - High exercise	Indoor activities - Cooking	Indoor activities - Rest
N	Valid	1095	1502	391	8965	7702	439	361	1721	18312
	Missing	17217	16810	17921	9347	10610	17873	17951	16591	0
Mean		13.3	19.2	21.3	15.1	12.6	91.2	12.3	35.4	8.9
Std. Deviation		19.9	31.1	51.3	102.9	25.6	378.8	36.9	111.6	19.0
Minimum		0.1	0.0	0.3	0.1	0.1	0.1	0.1	0.2	0.1
Maximum		297.5	532.1	707.6	2443.4	589.1	2099.5	575.9	1483.4	939.4
Percentiles	25.0	5.3	5.3	3.7	2.9	4.6	5.3	3.3	4.6	4.2
	50.0	8.6	9.7	8.9	4.5	7.1	7.8	7.5	7.8	5.9
	75.0	13.9	20.3	14.8	7.6	10.8	12.6	10.7	21.3	8.2
Skewness		7.1	6.2	8.0	16.7	9.2	4.7	11.5	7.6	21.2

A4. Table 6: Table 6: Personal exposure to $PM_{2.5}$ (µg/m³) concentrations associated with microenvironments at 5 minuets' time interval

		Indoors - Home	Indoors - friends/ relatives' homes	Indoors - Kitchen	Indoors - Office	Indoors - hospitality retailers	Indoors - others	Indoors - shopping areas	In vehicles	Outdoors - traffic areas	Outdoors - non-traffic areas	Hospital/ Medical related	Indoors exercising
N	Valid	28772	366	1493	5739	470	88	273	1075	1259	627	96	228
	Missing	0	28406	27279	23033	28302	28684	28499	27697	27513	28145	28676	28544
Mean		12.0	6.2	31.7	16.0	21.1	10.4	12.1	13.3	17.6	22.9	11.7	9.8
Std. Deviation		58.9	6.0	86.8	120.3	36.2	2.9	11.9	20.1	27.4	49.0	9.3	13.1
Minimum		0.1	1.0	0.2	0.1	0.1	2.6	1.0	0.1	0.0	0.3	1.8	0.1
Maximum		2099.5	88.4	1027.6	2443.4	368.2	14.6	79.4	297.5	332.8	707.6	57.3	106.8
Percentiles	25	4.1	3.7	5.2	3.0	4.5	9.2	5.1	5.3	5.3	6.1	5.9	3.7
	50	6.1	4.9	8.5	4.3	10.2	10.9	8.3	8.5	8.9	10.6	9.6	7.0
	75	8.7	6.1	22.4	7.0	17.4	12.3	14.3	13.8	18.1	19.9	13.3	10.4
Skewness		25.7	7.6	6.8	15.4	5.0	-1.2	2.7	7.0	4.8	7.7	2.9	4.4

A4. Table 7: Personal exposure to UFP (#/cc) concentrations associated with activities at 5 minutes time interval

		Travelling in vehicle	Outdoors commuting - Walking, running	Other outdoor activities	Working	Indoor activities - Light exercise	Indoor activities - Medium exercise	Indoor activities - High exercise	Indoor activities - Cooking	Indoor activities - Rest
N	Valid	612	745	261	5187	5236	214	144	1053	10267
	Missing	9676	9543	10027	5101	5052	10074	10144	9235	21
Mean		7015.7	5386.1	3560.1	4574.0	6749.6	7285.6	2117.8	25239.1	3187.3
Std. Deviation		12349.7	12397.2	5160.7	11790.9	17655.5	13548.2	1717.7	46824.0	8774.4
Minimum		164.0	60.7	349.8	23.0	26.2	280.0	47.9	136.3	36.4
Maximum		226629.2	165890.9	52106.4	205940.7	402874.3	74641.0	9490.5	550345.0	176235.0
Percentiles	25	1820.8	1063.5	1052.5	1110.5	1250.9	1266.7	849.8	1859.9	748.2
	50	3824.4	2109.7	2156.8	1915.8	2276.6	3023.9	1406.1	4961.5	1489.4
	75	7820.9	5382.0	3919.3	3586.3	5073.3	4621.8	3017.9	25359.3	2541.8
Skewness		10.3	8.1	5.5	9.0	9.2	3.1	1.4	3.8	9.1

A4. Table 8: Personal exposure to UFP (#/cc) concentrations associated with microenvironments at 5 minutes time interval

		Indoors - Home	Indoors - friends/ relatives' homes	Indoors - Kitchen	Indoors - Office	Indoors - hospitality retailers	Indoors - others	Indoors - shopping areas	In vehicles	Outdoors - traffic areas	Outdoors - non-traffic areas	Hospital/ Medical related	Indoors exercising
N	Valid	17247	38	809	3352	331	55	134	622	587	395	14	133
	Missing	0	17209	16438	13895	16916	17192	17113	16625	16660	16852	17233	17114
Mean		5020.6	5223.1	25661.8	3058.4	4018.2	2495.4	4383.1	6993.2	6029.5	3287.6	12671.0	1837.0
Std. Deviation		14100.6	16096.9	48679.6	8580.5	4703.7	13465.5	5573.8	12418.1	13192.0	5949.7	13608.6	1690.9
Minimum		23.0	910.0	91.6	54.9	211.0	451.3	342.4	164.0	65.8	60.7	1182.2	47.9
Maximum		402874.3	99903.4	550345.0	172053.7	36422.9	59111.4	25927.6	226629.2	165890.9	59940.6	44741.8	11432.8
Percentiles	25	944.7	1384.5	1595.2	890.8	820.6	1474.5	715.3	1747.1	1272.2	926.8	1715.0	834.8
	50	1836.2	1728.6	3940.2	1570.6	2298.8	1929.6	1747.2	3791.1	2397.0	1854.0	4000.6	1283.5
	75	3328.2	2058.9	24944.8	2585.1	4887.3	3266.8	6742.7	7717.4	6403.4	3452.9	23921.2	2353.8
Skewness		9.4	5.8	3.9	12.6	2.6	0.9	1.8	10.1	8.1	6.4	1.1	2.5

Appendix 5

Contribution to personal exposure associated with different activities and microenvironments

A5. Table 1: activities contribution% to personal exposure of BC for each of 40 subjects and for all subjects in total

ID	Travelling in vehicle	Outdoors commuting-Walking, running	Other outdoor activities	Working	Indoor activities-Light exercise	Indoor activities-Medium exercise	Indoor activities-High exercise	Indoor activities-Cooking	Indoor activities-Rest
ID1	4.5	1.6		57.5	14.8	0.0		9.5	12.1
ID2	21.6	4.9		2.0	37.5	4.4	2.5	3.4	23.6
ID3	23.2	0.8	1.6	24.5	8.1	0.6	1.7	1.9	37.8
ID4		6.4		37.7	27.3			8.3	20.2
ID5	11.1	12.0		21.8	4.5			0.5	50.0
ID6	20.3	11.6		13.8	14.5			0.1	39.7
ID7	2.7	15.7	0.0	20.8	17.3				43.5
ID8	19.7				35.4	5.0	5.4	6.1	28.3
ID9	1.2	6.3		0.5	65.4	0.9		5.9	19.9
ID10	3.6	12.5		20.4	27.9			1.5	34.1
ID11	17.8	3.7	1.3	16.0	12.3	0.4	0.9	6.1	41.3
ID12		5.6	2.7	28.6	17.9			18.9	26.3
ID13		4.9		16.9	26.1			2.4	49.7
ID14	8.9	4.6		34.9	17.2		12.5	5.3	16.6
ID15		9.2	6.6	43.6	13.7	3.5		11.4	12.1
ID16		2.6		17.0	19.9		7.3	1.9	51.3
ID17		4.8	3.5	6.2	21.5	2.2		17.3	44.6
ID18	10.1	1.1		1.2	7.6	3.6		13.4	62.9
ID19		13.4		36.5	19.4	1.8	2.7	0.9	25.2

ID20	0.3	4.4	17.2	25.7	6.7	1.7	1.4		42.8
ID21	4.8	6.0	7.1	15.9	27.8	2.2		9.5	26.7
ID22	1.9	4.7	1.9		31.6	3.9		3.7	52.2
ID23		12.7		20.3	29.4		3.4	4.7	29.6
ID24		14.0		7.6	14.4		2.3	27.0	34.7
ID25	27.3	1.5	5.2	7.9	20.0		2.3	17.9	17.9
ID26	11.6	1.4	2.2	39.2	9.1		1.4	6.5	28.6
ID27	11.1	21.1		51.4	4.7	0.7	4.8	5.5	0.7
ID28	24.2	3.4	1.7	19.6	16.8	3.7		3.0	27.4
ID29		16.2		11.4	26.9	0.5		8.2	36.8
ID30	1.8	0.3	13.2	21.9	25.7	5.6		11.8	19.7
ID31	0.4	1.3	1.7	2.7	34.6	0.3		3.9	55.2
ID32		4.9		6.3	8.1	0.4		2.1	78.2
ID33	0.8	0.9	4.3	2.7	12.4	2.0			76.8
ID34		1.9		29.1	13.6			1.4	54.0
ID35	2.4	6.3		12.4	61.1	0.7		7.5	9.6
ID36		0.8		14.6	14.2	0.8	1.2	10.3	58.2
ID37		1.0		20.7	19.5			0.3	58.4
ID38		1.7		11.9	7.2	0.7	0.9	5.8	71.9
ID39	0.6	1.3		22.7	5.8			7.1	62.5
ID40	0.1	1.3		10.0	18.2			1.3	69.1
Total	8.2	6.6	2.2	17.7	20.2	1.3	1.1	5.7	37.1

A5. Table 2: microenvironments contribution% to personal exposure of BC for each of 40 subjects and for all subjects in total

ID	Indoors-Home	Indoors-friends/relative's homes	Indoors-Kitchen	Indoors-Office	Indoors-hospitality retailers	Indoors-others	Indoors – shopping areas	In vehicles	Outdoors – traffic areas	Outdoors – non-traffic areas	Hospital / Medical related	Indoors exercising
ID1	84.2			10.0			1.3	2.1	2.4			
ID2	64.9			6.7		1.8		20.5	6.0			
ID3	41.7	1.3		25.1	3.5		1.1	23.4		2.1		1.7
ID4	58.4			35.2					6.4			
ID5	55.3		0.5	21.1				11.1	12.0			
ID6	42.6	0.3		14.4	10.9			20.3	11.6			
ID7	53.3		0.5	21.0	6.1		0.9	2.7	15.5	0.0		
ID8	58.4			16.4		5.4		19.7				
ID9	83.9		6.0				1.9	1.2	7.0			
ID10	43.1		0.4	21.1	19.9			3.6	8.7	3.3		
ID11	50.5		10.5	12.8	1.0		0.5	17.8	5.0		0.9	0.9
ID12	57.2		18.9	10.5	0.7		4.9		5.0	2.7		
ID13	87.9		2.4	5.3	0.0	0.1			4.2			
ID14	46.4		19.9	4.5	3.2			8.9	4.6			12.5
ID15	67.8		9.1	4.7			0.9		8.8	6.6	2.1	
ID16	20.7	49.8	1.0	17.0	1.6				2.6			7.3

ID17	65.8	1.4	18.6	1.3	0.2		1.7			8.3	2.6	
ID18	74.4	7.9		1.2			5.2	9.9	0.2	1.1		
ID19	61.2		1.2	20.8	0.5		1.6		13.4		1.2	
ID20	47.1			25.8	3.4		0.3	0.1	0.7	21.3		1.4
ID21	56.2	0.1	21.7	1.1	0.4		2.1	4.8	6.0	7.7		
ID22	87.5		3.9					1.9	1.9	4.8		
ID23	52.9			8.4	19.8		2.8		12.7			3.4
ID24	42.2		26.2	7.3	8.2				13.9			2.3
ID25	52.4			7.9	1.2		0.6	27.3	5.4	5.2		
ID26	51.7	1.8	5.4	25.9				11.6	1.4	2.2		
ID27	30.0			5.9				20.9	11.2			31.9
ID28	59.3			9.4				24.2	4.4	1.7	0.9	
ID29	69.6			14.1			0.1		16.2			
ID30	55.1		18.0	5.3			3.3	1.8		16.5		
ID31	83.0		9.7	1.3				0.4		5.6		
ID32	83.3		2.1	6.3	3.4				4.4	0.5		
ID33	89.3				0.2		4.4	0.8	0.6	4.6		
ID34	74.2	2.1	3.8	13.5	4.0	0.6	0.7		1.2			
ID35	71.3		7.5	12.4				2.4	6.3			
ID36	78.1		14.1	6.9					0.8			
ID37	93.7		0.3	4.1	1.3				0.6			
ID38	85.1			11.9			0.4		1.7			0.9
ID39	78.2	5.8	7.1	2.7				0.6	0.9	0.3	4.3	
ID40	92.3		2.1	2.9		0.2	1.5	0.1	0.9			
Total	59.8	0.9	4.2	12.6	2.8	0.2	0.7	8.4	6.2	2.7	0.2	1.2

A5. Table 3: activities contribution% to personal exposure of $PM_{2.5}$ for each of 40 subjects and for all subjects in total

ID	Travelling in vehicle	Outdoors commuting-Walking, running	Other outdoor activities	Working	Indoor activities-Light exercise	Indoor activities-Medium exercise	Indoor activities-High exercise	Indoor activities-Cooking	Indoor activities-Rest
ID1	0.7	0.2		68.8	15.0	0.0		9.2	6.1
ID2	11.6	2.1		2.7	34.6	4.3	2.8	2.6	39.5
ID3	3.6		0.5	5.8	1.5	72.1	1.1	1.5	13.8
ID4		6.7		26.1	27.8			21.3	18.1
ID5	5.6	7.7		19.1	5.2			1.1	61.4
ID6	7.0	6.9		17.1	9.7				59.2
ID7	1.6	4.9	0.8	14.1	24.5				54.1
ID8	12.8				40.4	3.0	2.1	12.6	29.2
ID9	8.4	33.5		1.4	29.8	2.1		6.6	18.3
ID10	1.7	15.6		16.5	23.5			3.3	39.4
ID11	9.7	6.5	0.6	17.2	19.3	0.4		8.2	38.1
ID12		5.8	0.6	21.2	27.9			31.1	13.3
ID13		3.9		10.3	27.8			4.6	53.4
ID14	2.1	18.1		30.9	13.6		1.7	16.2	17.4
ID15		6.6	1.5	26.3	15.8	1.5		41.6	6.7
ID16		3.5		21.1	31.9		8.4	2.0	33.0
ID17		2.7	3.9	1.9	22.2	2.1		20.2	47.0
ID18	15.7	1.8		0.9	6.6	1.1		13.1	60.7
ID19		9.1		19.3	25.8	1.3	0.6	0.3	43.7

ID20	0.1	4.5	3.4	82.1	1.6	0.0	0.2		8.1
ID21	0.2	12.2	25.1	10.8	20.3	1.6		7.8	21.9
ID22	0.6	8.8	3.8		27.8	2.0		2.5	54.5
ID23		1.2		47.0	11.0		0.2	25.1	15.5
ID24		14.1		6.6	8.0		0.7	29.3	41.4
ID25	7.2	9.5		20.9	16.8		18.7	4.3	22.6
ID26	4.5	2.6	1.9	27.4	13.3		1.0	7.4	41.9
ID27	9.7	5.6		22.2	23.5	1.5	3.2	5.5	28.8
ID28	16.5	8.1	1.2	16.4	16.8	4.2		4.1	32.5
ID29		12.6		11.0	29.0	0.3		13.6	33.4
ID30	1.3	1.2	4.2	18.5	22.0	1.8		26.3	24.8
ID31	3.2	10.8	4.9	4.7	39.2	0.4		3.3	33.5
ID32		4.1		4.1	12.2	0.1		1.7	77.7
ID33	3.2	4.9	3.1	4.6	21.0	2.2			61.1
ID34		14.1		39.6	13.4			1.0	31.8
ID35	1.7	2.8		12.4	33.8	2.9		30.2	16.1
ID36		2.2		11.6	28.7	2.0	0.5	31.7	23.2
ID37		4.4		33.7	31.5			1.4	29.1
ID38		15.3		6.9	12.9	0.9	1.9	13.4	48.7
ID39	0.6	0.7		1.9	1.1			92.2	3.5
ID40	0.3	12.0		19.0	26.3			1.0	41.3
Total	2.4	4.7	1.4	22.1	15.9	6.5	0.7	19.5	26.8

A5. Table 4: microenvironments contribution% to personal exposure of $PM_{2.5}$ for each of 40 subjects and for all subjects in total

ID	Indoors-Home	Indoors-friends/ relative's homes	Indoors-Kitchen	Indoors-Office	Indoors-hospitality retailers	Indoors-others	Indoors – shopping areas	In vehicles	Outdoors – traffic areas	Outdoors – non-traffic areas	Hospital / Medical related	Indoors exercising
ID1	97.5			0.9			0.9	0.4	0.4			
ID2	77.3			4.9		4.1		10.3	3.5			
ID3	88.5			6.1			0.1	3.6		0.5		1.1
ID4	69.0			24.3					6.7			
ID5	67.3		1.1	18.4				5.6	7.6			
ID6	65.1	0.2		18.4	2.4			7.0	6.9			
ID7	66.0		0.5	15.3	11.6		0.6	1.6	3.6	0.8		
ID8	67.2			17.9		2.1		12.8				
ID9	49.4		6.6					8.4	35.6			
ID10	60.8		3.0	16.8	2.2			1.7	11.1	4.5		
ID11	48.3		15.3	15.9	1.9		0.8	9.7	7.0		1.1	
ID12	52.9		31.1	8.5	0.2		2.1		4.5	0.6		
ID13	80.6		4.6	13.3	0.2				1.4			
ID14	41.7		28.5	7.9	0.0			2.1	18.1			1.7
ID15	37.0		40.7	13.5			0.2		6.5	1.5	0.6	
ID16	39.3	17.0	1.1	21.1	9.6				3.5			8.4

ID17	68.9	0.5	21.6	0.7	0.3		0.8			6.6	0.6	
ID18	75.5	2.2		0.9			3.9	15.6	0.1	1.8		
ID19	73.0		0.3	11.3	1.8		4.0		9.1		0.5	
ID20	8.9			82.1	0.4		0.1	0.1	0.4	7.8		0.2
ID21	42.7	0.2	15.5	1.3	0.3		1.5	0.2	12.1	26.2		
ID22	84.2		2.6					0.6	2.3	10.2		
ID23	93.5			0.6	4.1		0.4		1.2			0.2
ID24	48.0		28.7	6.4	2.1				14.1			0.7
ID25	60.8			20.9	1.5		0.0	7.2	9.5			
ID26	64.5		7.4	19.1				4.5	2.6	1.9		
ID27	77.0			3.5				9.7	5.6			4.1
ID28	61.4			10.5				16.5	9.0	1.2	1.4	
ID29	69.8			17.4			0.2		12.6			
ID30	59.0		32.1	0.6			1.6	1.3		5.4		
ID31	64.7		11.1	3.0				3.2		18.0		
ID32	88.3		1.7	4.1	1.7				3.3	0.8		
ID33	79.0				0.5		9.4	3.2	1.7	6.3		
ID34	63.4	0.4	2.6	15.0	4.6	0.7	1.1		12.2			
ID35	52.8		30.3	12.4				1.7	2.8			
ID36	54.1		39.9	3.8					2.2			
ID37	78.1		1.4	5.7	11.4				3.5			
ID38	75.6			6.9			0.2		15.3			1.9
ID39	50.7	4.9	18.2	3.9				6.6	6.1		9.6	
ID40	77.8		2.7	7.8		0.2	2.9	0.3	8.1			
Total	62.2	0.4	8.5	16.5	1.8	0.2	0.6	2.6	4.0	2.6	0.2	0.4

A5. Table 5: activities contribution% to personal exposure of UFP for each of 40 subjects and for all subjects in total

ID	Travelling in vehicle	Outdoors commuting-Walking, running	Other outdoor activities	Working	Indoor activities-Light exercise	Indoor activities-Medium exercise	Indoor activities-High exercise	Indoor activities-Cooking	Indoor activities-Rest
ID1	1.2	1.0		65.8	14.1	0.1		7.2	10.6
ID2	14.8	4.2		1.1	51.8	4.8	1.5	3.5	18.2
ID3	19.3	4.3		48.1	17.1				11.2
ID4		1.7		37.3	5.1			13.6	42.3
ID5	10.7	14.5		33.8	10.3			0.4	30.3
ID6	48.9	12.2		13.2	15.6				10.2
ID7	1.9	9.5		29.0	13.8				45.7
ID8	6.7				73.5	1.9		7.9	10.0
ID9		6.0			59.6			18.0	16.3
ID10	1.6	9.4		12.4	34.4			1.3	40.9
ID11	6.1	0.7	0.5	10.1	20.1	0.3		44.5	17.7
ID12		1.4		22.4	20.1			39.0	17.1
ID13		1.7		4.8	34.2		0.2	20.9	38.3
ID14	1.0	0.4		32.8	41.3		0.4	15.9	8.1
ID15		0.1	0.6	27.9	26.9			41.3	3.1
ID16		2.2		82.7	11.6		1.2	0.2	2.1
ID17		0.1	0.2	0.3	22.4			34.0	42.9
ID18	2.6	0.9			5.7	0.2		14.3	76.3

ID19		6.0		23.0	35.3			1.2	34.4
ID20	0.1	4.5	27.3	6.4	25.2	0.5	1.2		34.7
ID21		1.5	4.9	13.0	20.3	2.9		41.4	16.0
ID22	0.7	2.2	2.5		22.4			42.2	29.9
ID23		1.1		20.2	19.2		0.0	29.7	29.9
ID24		22.8		26.6	7.4			16.8	26.4
ID25	16.9	1.3	3.8	2.6	24.4		1.3	20.0	29.7
ID26	6.0	2.2	0.8	35.7	15.8			22.6	16.9
ID27	8.3	16.1		25.2	4.1	17.8	1.4		27.0
ID28	26.1	0.7		20.0	6.5				46.7
ID29	10.8			9.1	31.7	1.0		21.5	25.9
ID30	0.1	0.3	5.3	19.4	65.6	0.9		1.1	7.2
ID31		3.3	6.7	10.8	70.0				9.2
ID32					22.2	3.1			74.7
ID33	3.5		9.0		21.3				66.2
ID34		5.4		51.7	20.5			2.2	20.2
ID35	3.4	4.7		7.1	42.0	5.6		27.4	9.7
ID36		2.1		7.1			9.2	65.5	16.0
ID37									
ID38	1.1			4.3	10.8	6.9	0.4	19.3	57.2
ID39	1.2	0.4		22.6				69.6	6.2
ID40	1.2	15.2		10.1	39.7			8.7	25.2
Total	3.3	3.2	0.6	18.2	27.3	1.2	0.2	20.6	25.3

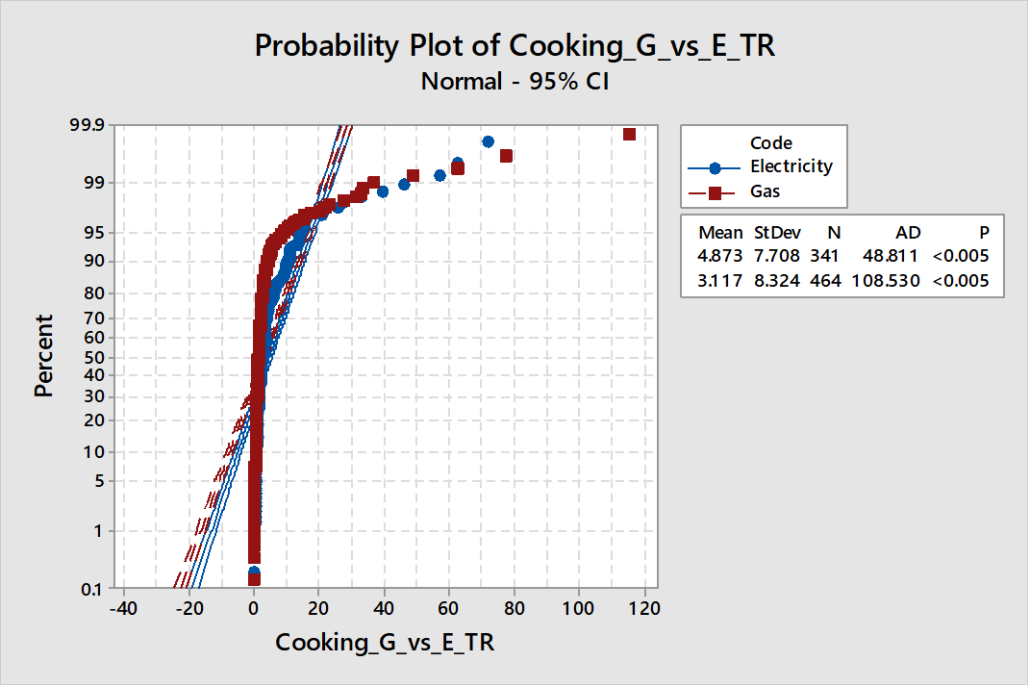
A5. Table 6: microenvironments contribution% to personal exposure of UFP for each of 40 subjects and for all subjects in total

ID	Indoors-Home	Indoors-friends/relative's homes	Indoors-Kitchen	Indoors-Office	Indoors-hospitality retailers	Indoors-others	Indoors – shopping areas	In vehicles	Outdoors – traffic areas	Outdoors – non-traffic areas	Hospital / Medical related	Indoors exercising
ID1	95.7			2.3			0.8	0.5	0.8			
ID2	76.1			3.4		1.4		14.4	4.6			
ID3	11.4	6.4		43.7	12.7		2.0	20.0		3.6		
ID4	66.1			32.2					1.7			
ID5	49.5		0.4	25.0				10.7	14.5			
ID6	12.2			19.5	7.3			48.9	12.2			
ID7	58.0			29.0	1.6			1.9	9.5			
ID8	80.6			12.7				6.7				
ID9	75.9		18.0						6.0			
ID10	66.6		0.6	12.4	9.3			1.6	5.7	3.7		
ID11	26.7		53.5	9.9	2.6			6.1	1.2			
ID12	55.4		39.0	3.8	0.6		0.4		0.7			
ID13	72.5		20.9	5.3		0.0			1.1			0.2
ID14	53.3		43.4	1.4				1.0	0.4			0.4
ID15	55.9		41.0	0.3					0.1	0.6	2.1	
ID16	11.4	0.9	0.2	82.7	1.4				2.2			1.2
ID17	64.8	0.4	34.0	0.3						0.3	0.2	
ID18	94.5						2.0	2.6		0.9		
ID19	76.5		1.2	12.6			3.6		6.0			

ID20	58.7			6.4	0.3		0.5	0.0	0.9	31.9		1.2
ID21	38.0		52.1	2.1	1.0				2.0	4.9		
ID22	52.3		42.2					0.7	0.5	4.2		
ID23	96.2			0.5	2.0		0.1		1.1			0.0
ID24	53.7		14.7	8.9					22.7			
ID25	70.0			2.6	2.5			16.9	4.1	3.8		
ID26	61.7		19.3	11.3				5.1	1.9	0.7		
ID27	62.3			4.2				17.3	7.1			9.1
ID28	54.8			17.2				26.1	1.9			
ID29	76.9			12.1			0.2		10.8			
ID30	89.4		2.9	1.2			0.6	0.1		5.9		
ID31	86.2		3.8							10.0		
ID32	99.5				0.5							
ID33	78.0						9.5	3.5		9.0		
ID34	51.4		2.4	39.2	4.7	0.1			2.2			
ID35	57.3		27.4	7.1				3.4	4.7			
ID36	31.0		65.5	1.4					2.1			
ID37												
ID38	94.3			4.3					1.1			0.4
ID39	27.9		69.6	0.8				1.2	0.2	0.2		
ID40	51.3		20.6	0.8		0.6	10.4	1.2	15.0			
Total	66.9	0.2	16.0	7.9	1.0	0.1	0.5	3.4	2.7	1.0	0.1	0.2

Appendix 6

Outputs for chapter 5 results



A6. Figure 1: Probability Plot for cooking with gas and cooking with electricity for houses located near busy roads - BC

Two-Sample T-Test and CI: Cooking_G_vs_E_TR, Code

```
Two-sample T for Cooking_G_vs_E_TR

Code           N  Mean  StDev  SE Mean
Electricity  341  4.87   7.71     0.42
Gas          464  3.12   8.32     0.39


Difference = μ (Electricity) - μ (Gas)
Estimate for difference:  1.755
95% CI for difference:  (0.639, 2.872)
T-Test of difference = 0 (vs ≠): T-Value = 3.09  P-Value = 0.002  DF = 761
```

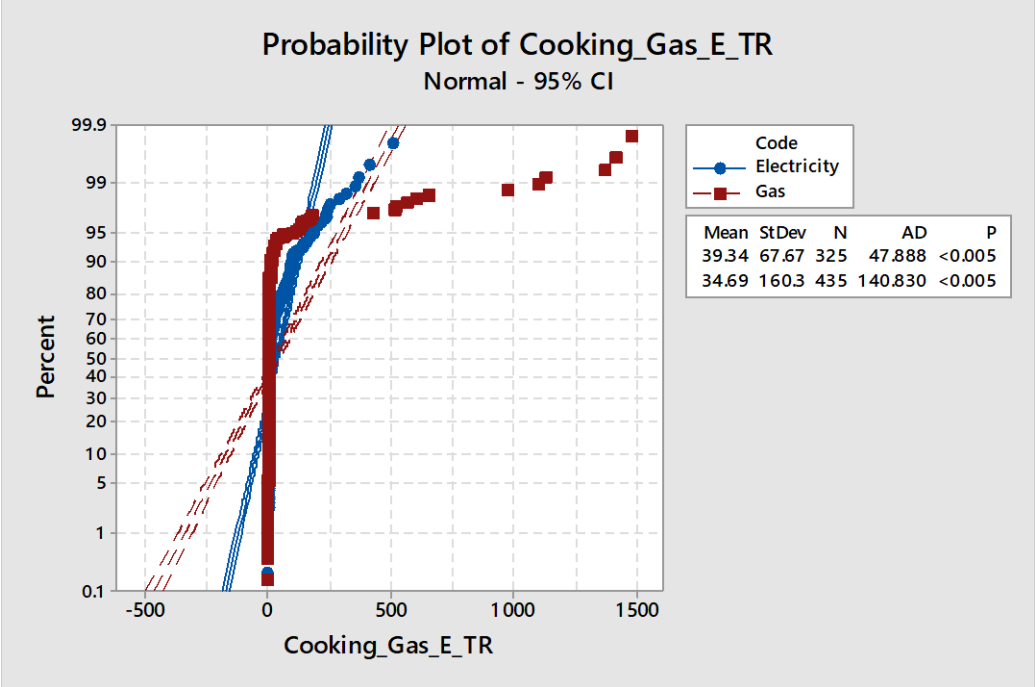
A6. Figure 2: Two sample t-test output for cooking with gas stove and cooking with electricity for houses located near busy roads - BC

Mann-Whitney Test and CI: Cooking_Gas_TR, Cooking_Electricity_TR

	N	Median
Cooking_Gas_TR	464	1.5300
Cooking_Electricity_TR	341	2.7650

Point estimate for η1 - η2 is -1.0890
95.0 Percent CI for η1 - η2 is (-1.3269,-0.8649)
W = 155718.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

A6. Figure 3: Mann Whitney test output for cooking with gas stove and cooking with electricity for houses located near busy roads – BC



A6. Figure 4: Probability Plot for cooking with gas and cooking with electricity for houses located near busy roads – $PM_{2.5}$

Two-Sample T-Test and CI: Cooking_Gas_E_TR, Code

```
Two-sample T for Cooking_Gas_E_TR

Code           N  Mean  StDev  SE Mean
Electricity  325  39.3   67.7      3.8
Gas          435    35    160      7.7


Difference = μ (Electricity) - μ (Gas)
Estimate for difference:  4.65
95% CI for difference:  (-12.14, 21.45)
T-Test of difference = 0 (vs ≠): T-Value = 0.54  P-Value = 0.587  DF = 618
```

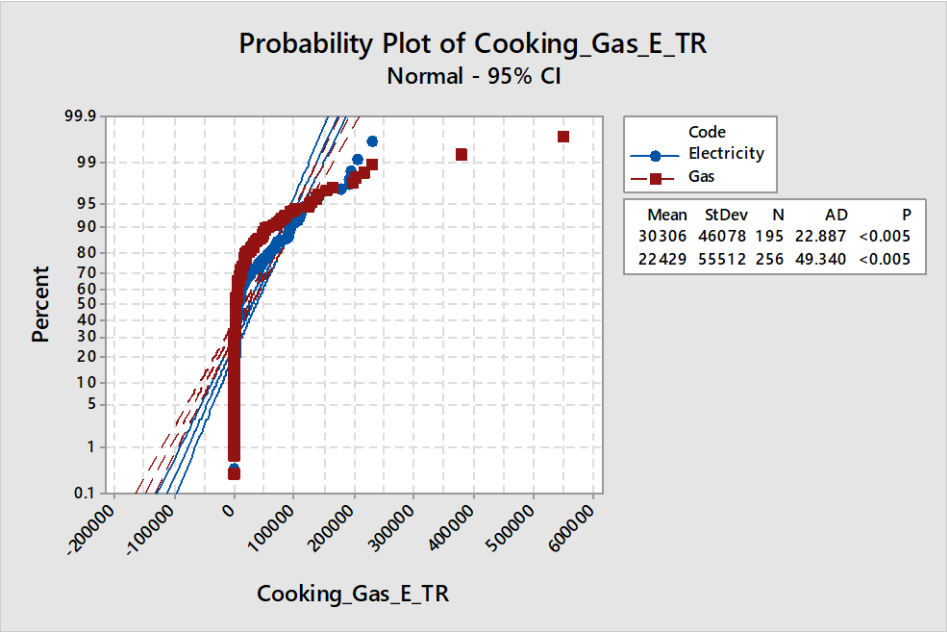
A6. Figure 5: Two sample t-test output for cooking with gas stove and cooking with electricity for houses located near busy roads - $PM_{2.5}$

Mann-Whitney Test and CI: Cooking_Gas_E_TR_Electricity, Cooking_Gas_E_TR_Gas

```
                                N  Median
Cooking_Gas_E_TR_Electricity  325  10.219
Cooking_Gas_E_TR_Gas          435   6.091


Point estimate for η1 - η2 is 4.475
95.0 Percent CI for η1 - η2 is (3.543,5.543)
W = 155737.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

A6. Figure 6: Mann Whitney test output for cooking with gas stove and cooking with electricity for houses located near busy roads – $PM_{2.5}$



A6. Figure 7: Probability Plot for cooking with gas and cooking with electricity for houses located near busy roads – UFP

Two-Sample T-Test and CI: Cooking_Gas_E_TR, Code

```
Two-sample T for Cooking_Gas_E_TR

Code           N   Mean  StDev  SE Mean
Electricity  195  30306  46078     3300
Gas          256  22429  55512     3469


Difference = μ (Electricity) - μ (Gas)
Estimate for difference:  7877
95% CI for difference:  (-1533, 17287)
T-Test of difference = 0 (vs ≠): T-Value = 1.65  P-Value = 0.101  DF = 445
```

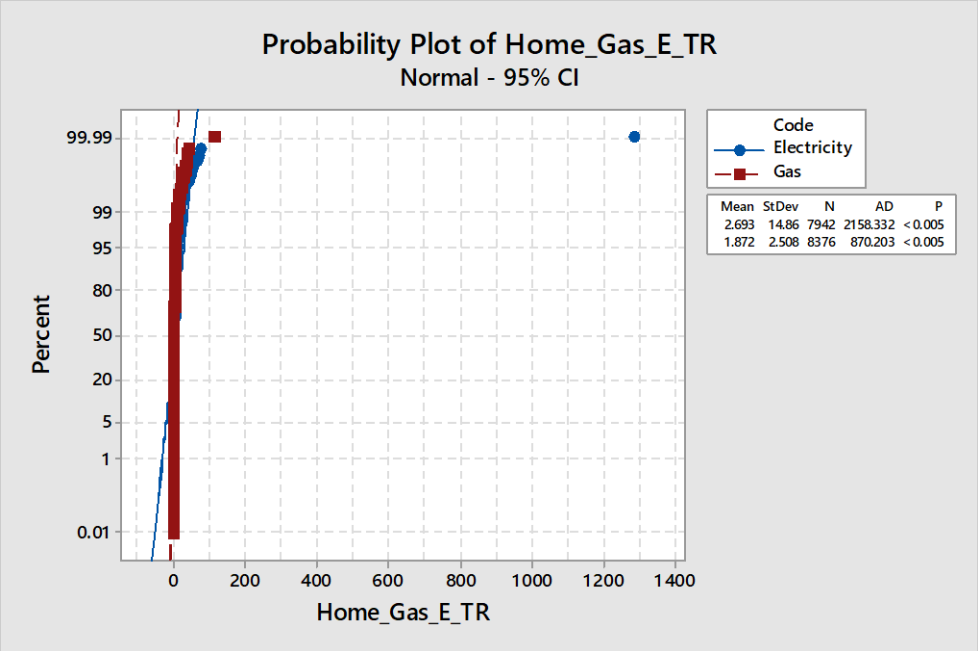
A6. Figure 8:Two sample t-test output for cooking with gas stove and cooking with electricity for houses located near busy roads - UFP

Mann-Whitney Test and CI: Cooking_Gas_E_TR_Electricity, Cooking_Gas_E_TR_Gas

	N	Median
Cooking_Gas_E_TR_Electricity	195	6829.8
Cooking_Gas_E_TR_Gas	256	3674.1

Point estimate for η1 - η2 is 1410.1
95.0 Percent CI for η1 - η2 is (555.6,3451.6)
W = 48866.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0005

A6. Figure 9: Mann Whitney test output for cooking with gas stove and cooking with electricity for houses located near busy roads – UFP



A6. Figure 10: Probability Plot for time spent at houses using gas stove compared to houses using electricity stove located near busy roads – BC

Two-Sample T-Test and CI: Home_Gas_E_TR, Code

```
Two-sample T for Home_Gas_E_TR

Code            N  Mean  StDev  SE Mean
Electricity  7942   2.7   14.9     0.17
Gas          8376  1.87   2.51    0.027


Difference = μ (Electricity) - μ (Gas)
Estimate for difference:  0.821
95% CI for difference:  (0.490, 1.152)
T-Test of difference = 0 (vs ≠): T-Value = 4.86  P-Value = 0.000  DF = 8369
```

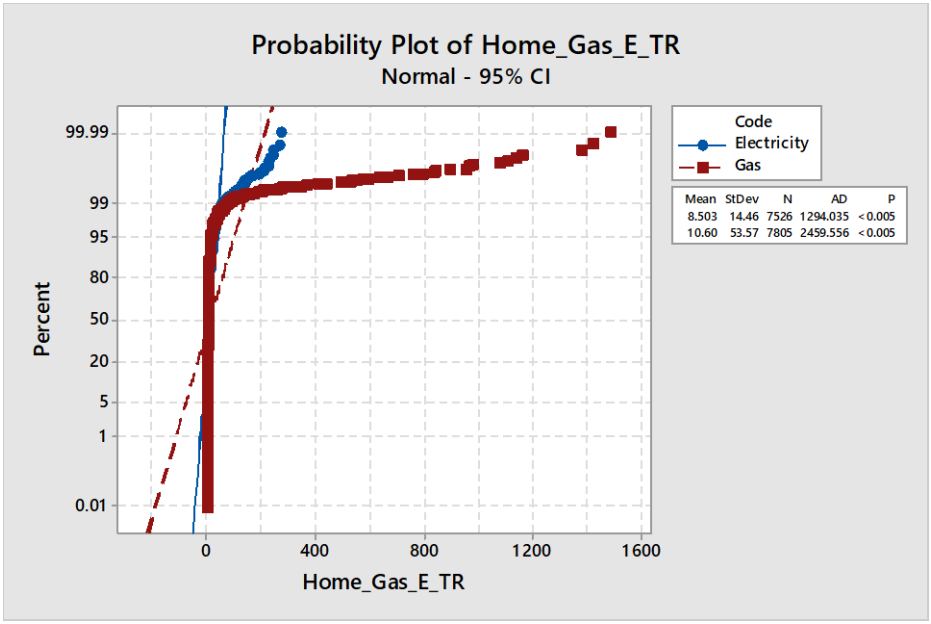
A6. Figure 11: Two sample t-test output for time spent at houses using gas stove compared to houses using electricity stove located near busy roads – BC

Mann-Whitney Test and CI: Gas, Electricity

```
               N  Median
Gas         8376  1.4345
Electricity 7942  1.5330


Point estimate for η1 - η2 is -0.1400
95.0 Percent CI for η1 - η2 is (-0.1749,-0.1051)
W = 65995011.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

A6. Figure 12: Mann Whitney test output for time spent at houses using gas stove compared to houses using electricity stove located near busy roads – BC



A6. Figure 13: Probability Plot for time spent at houses using gas stove compared to houses using electricity stove located near busy roads – $PM_{2.5}$

Two-Sample T-Test and CI: Home_Gas_E_TR, Code

```
Two-sample T for Home_Gas_E_TR

Code           N  Mean  StDev  SE Mean
Electricity  7526   8.5   14.5     0.17
Gas          7805  10.6   53.6     0.61


Difference = μ (Electricity) - μ (Gas)
Estimate for difference:  -2.099
95% CI for difference:  (-3.331, -0.866)
T-Test of difference = 0 (vs ≠): T-Value = -3.34  P-Value = 0.001  DF = 8975
```

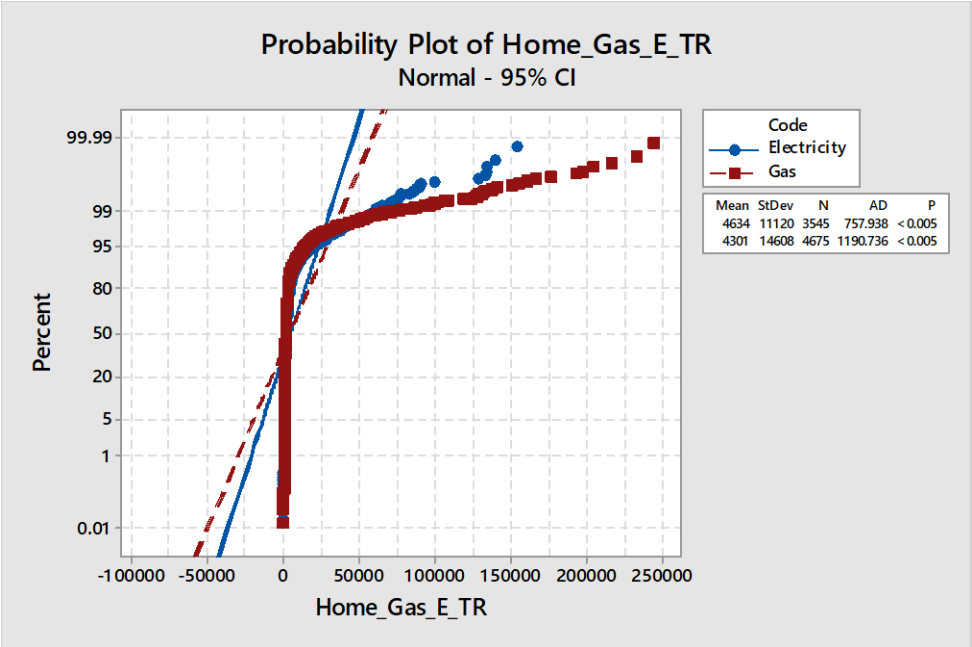
A6. Figure 14: Two sample t-test output for time spent at houses using gas stove compared to houses using electricity stove located near busy roads – $PM_{2.5}$

Mann-Whitney Test and CI: Home_Gas_TR, Home_E_TR

	N	Median
Home_Gas_TR	7805	5.9970
Home_E_TR	7526	5.7700

Point estimate for η1 − η2 is −0.1040
95.0 Percent CI for η1 − η2 is (−0.2122,0.0032)
W = 59311896.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0571
The test is significant at 0.0571 (adjusted for ties)

A6. Figure 15: Mann Whitney test output for time spent at houses using gas stove compared to houses using electricity stove located near busy roads – $PM_{2.5}$



A6. Figure 16: Probability Plot for time spent at houses using gas stove compared to houses using electricity stove located near busy roads – UFP

Two-Sample T-Test and CI: Home_Gas_E_TR, Code

```
Two-sample T for Home_Gas_E_TR

Code           N  Mean  StDev  SE Mean
Electricity  3545  4634  11120      187
Gas          4675  4301  14608      214


Difference = μ (Electricity) - μ (Gas)
Estimate for difference:  333
95% CI for difference:  (-224, 889)
T-Test of difference = 0 (vs ≠): T-Value = 1.17  P-Value = 0.241  DF = 8217
```

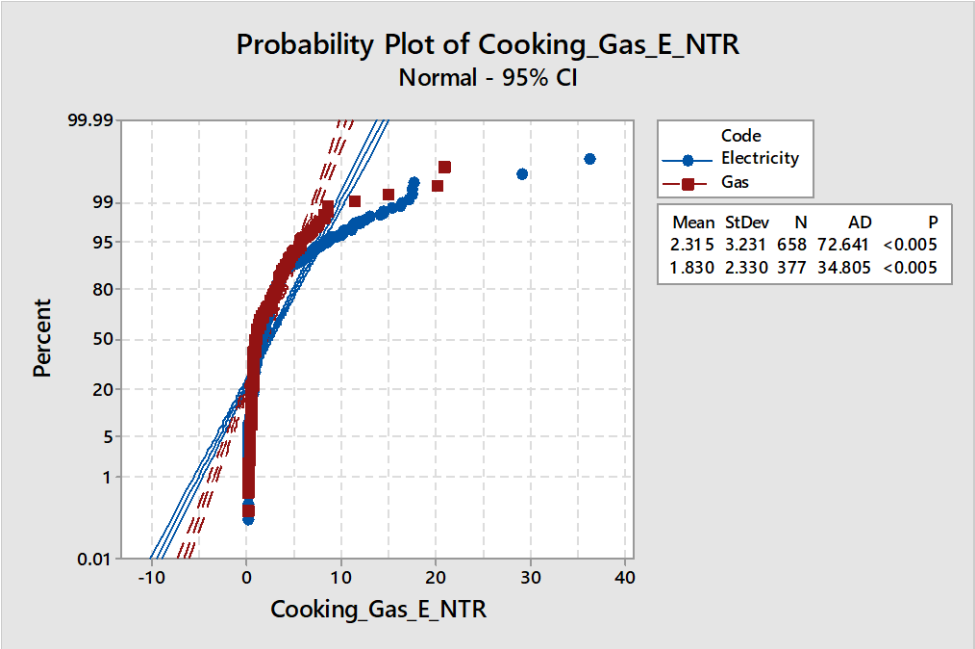
A6. Figure 17: Two sample t-test output for time spent at houses using gas stove compared to houses using electricity stove located near busy roads – UFP

Mann-Whitney Test and CI: Home_Gas_E_TR_Electricity, Home_Gas_E_TR_Gas

```
                            N  Median
Home_Gas_E_TR_Electricity  3545  1801.7
Home_Gas_E_TR_Gas          4675  1445.3


Point estimate for η1 - η2 is 316.6
95.0 Percent CI for η1 - η2 is (259.0,374.6)
W = 15718294.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

A6. Figure 18: Mann Whitney test output for time spent at houses using gas stove compared to houses using electricity stove located near busy roads – UFP



A6. Figure 19: Probability Plot for cooking with gas and cooking with electricity for houses located near quiet roads – BC

Two-Sample T-Test and CI: Cooking_Gas_E_NTR, Code

Two-sample T for Cooking_Gas_E_NTR

Code	N	Mean	StDev	SE Mean
Electricity	658	2.31	3.23	0.13
Gas	377	1.83	2.33	0.12

Difference = μ (Electricity) - μ (Gas)
Estimate for difference: 0.485
95% CI for difference: (0.144, 0.826)
T-Test of difference = 0 (vs ≠): T-Value = 2.79 P-Value = 0.005 DF = 980

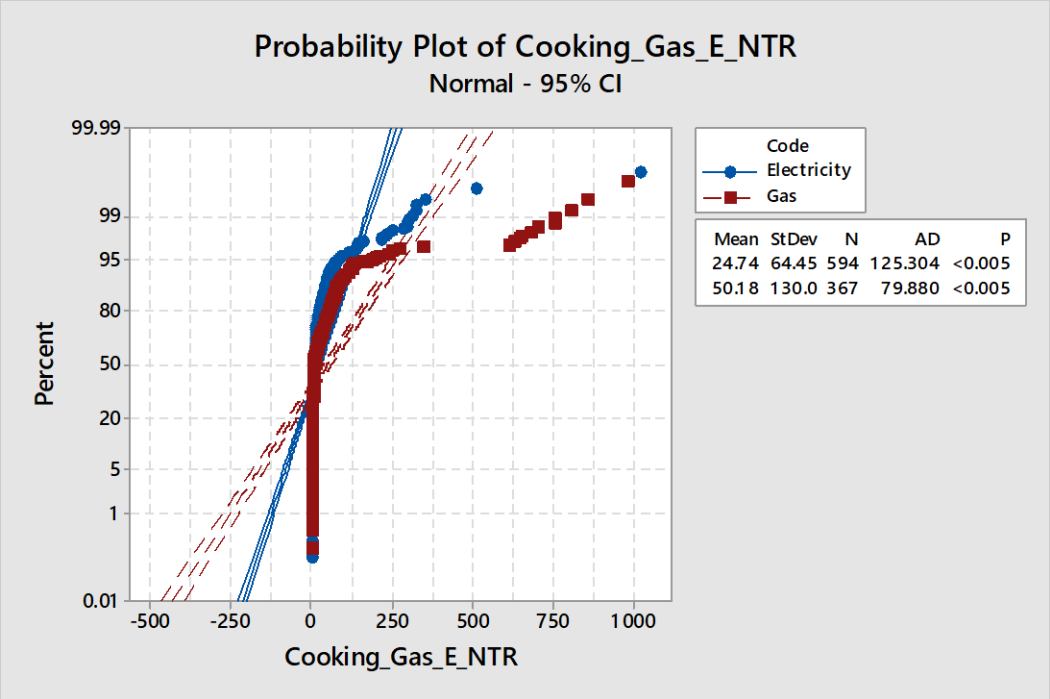
A6. Figure 20: Two sample t-test output for cooking with gas and cooking with electricity for houses located near quiet roads – BC

Mann-Whitney Test and CI: Cooking_Gas_NTR, Cooking_Electricity_NTR

	N	Median
Cooking_Gas_NTR	377	0.8820
Cooking_Electricity_NTR	658	1.4310

Point estimate for η1 - η2 is -0.1970
95.0 Percent CI for η1 - η2 is (-0.3410,-0.0630)
W = 181476.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0028
The test is significant at 0.0028 (adjusted for ties)

A6. Figure 21: Mann Whitney test output for cooking with gas and cooking with electricity for houses located near quiet roads – BC



A6. Figure 22: Probability Plot for cooking with gas and cooking with electricity for houses located near quiet roads – $PM_{2.5}$

Mann-Whitney Test and CI: Cooking_Gas_NTR, Cooking_E_NTR

	N	Median
Cooking_Gas_NTR	367	8.744
Cooking_E_NTR	594	8.768

Point estimate for η1 − η2 is 1.536
95.0 Percent CI for η1 − η2 is (0.565,2.640)
W = 189483.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0019
The test is significant at 0.0019 (adjusted for ties)

A6. Figure 23: Mann Whitney test output for cooking with gas and cooking with electricity for houses located near quiet roads – $PM_{2.5}$

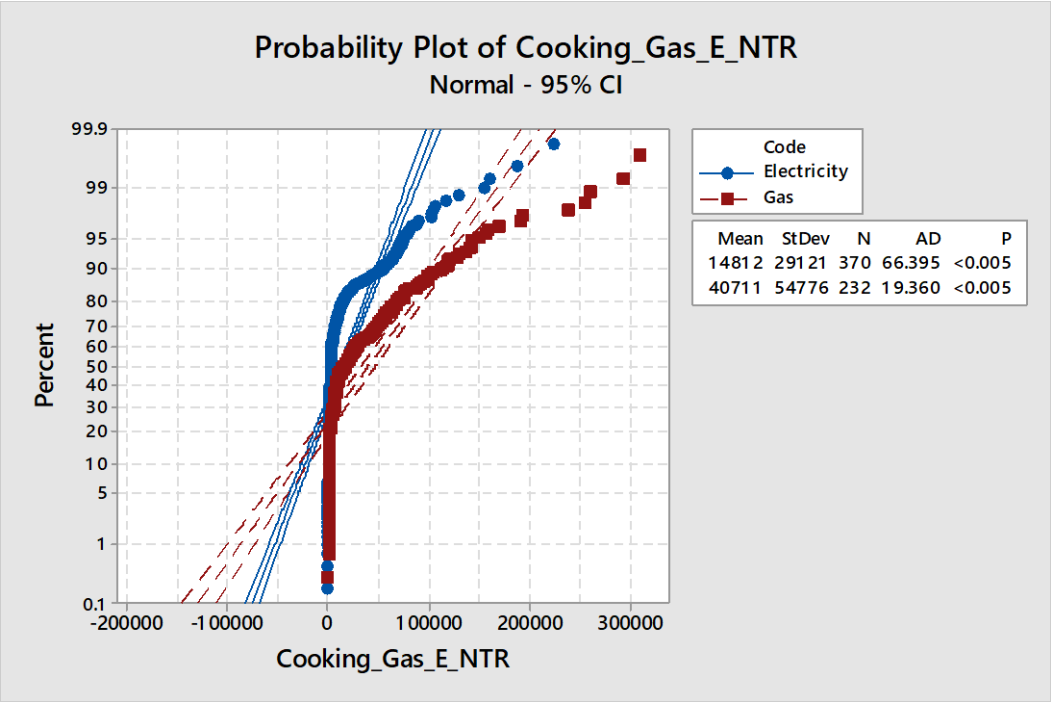
Two-Sample T-Test and CI: Cooking_Gas_E_NTR, Code

Two-sample T for Cooking_Gas_E_NTR

Code	N	Mean	StDev	SE Mean
Electricity	594	24.7	64.4	2.6
Gas	367	50	130	6.8

Difference = μ (Electricity) − μ (Gas)
Estimate for difference: -25.44
95% CI for difference: (-39.76, -11.13)
T-Test of difference = 0 (vs ≠): T-Value = -3.49 P-Value = 0.001 DF = 478

A6. Figure 25: Two sample t-test output for cooking with gas and cooking with electricity for houses located near quiet roads – $PM_{2.5}$



A6. Figure 26: Probability Plot for cooking with gas and cooking with electricity for houses located near quiet roads – UFP

Two-Sample T-Test and CI: Cooking_Gas_E_NTR, Code

```
Two-sample T for Cooking_Gas_E_NTR

Code           N   Mean  StDev  SE Mean
Electricity  370  14812  29121     1514
Gas          232  40711  54776     3596


Difference = μ (Electricity) - μ (Gas)
Estimate for difference:  -25899
95% CI for difference:  (-33576, -18221)
T-Test of difference = 0 (vs ≠): T-Value = -6.64  P-Value = 0.000  DF = 313
```

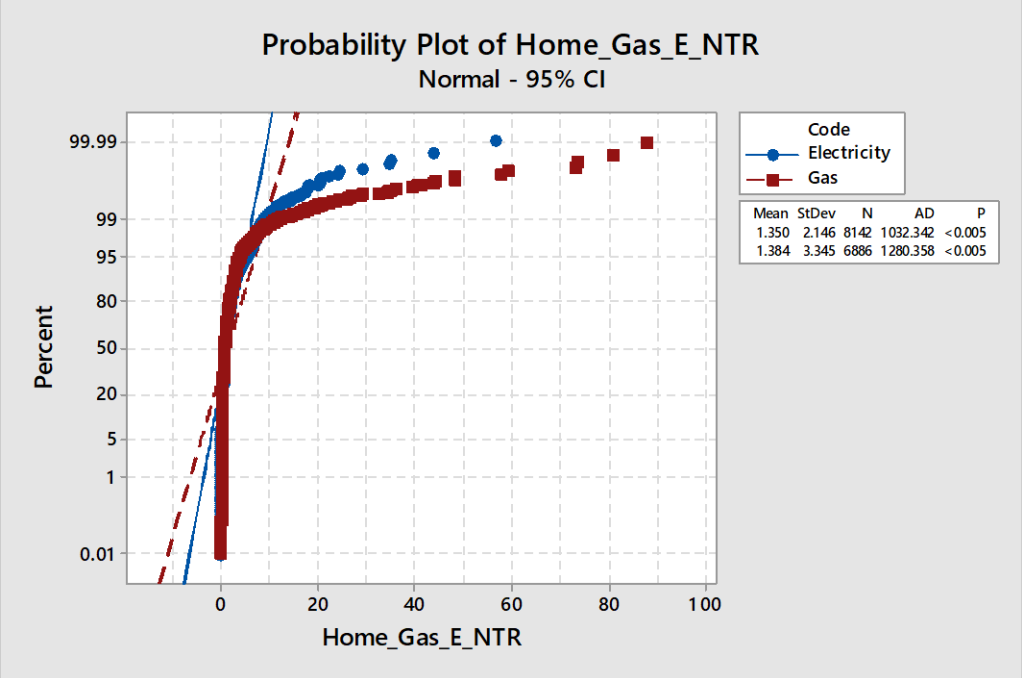
A6. Figure 27: Two sample t-test output for cooking with gas and cooking with electricity for houses located near quiet roads – UFP

Mann-Whitney Test and CI: Cooking_Gas_NTR, Cooking_E_NTR

	N	Median
Cooking_Gas_NTR	232	17439
Cooking_E_NTR	370	3184

Point estimate for η1 - η2 is 8020
95.0 Percent CI for η1 - η2 is (5671,12549)
W = 87585.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000

A6. Figure 28: Mann Whitney test output for cooking with gas and cooking with electricity for houses located near quiet roads – UFP



A6. Figure 29: Probability Plot for time spent at houses using gas stove compared to houses - BC

Two-Sample T-Test and CI: Home_Gas_E_NTR, Code

```
Two-sample T for Home_Gas_E_NTR

Code            N  Mean  StDev  SE Mean
Electricity  8142  1.35   2.15    0.024
Gas          6886  1.38   3.35    0.040


Difference = μ (Electricity) - μ (Gas)
Estimate for difference:  -0.0337
95% CI for difference:  (-0.1254, 0.0581)
T-Test of difference = 0 (vs ≠): T-Value = -0.72  P-Value = 0.472  DF = 11348
```

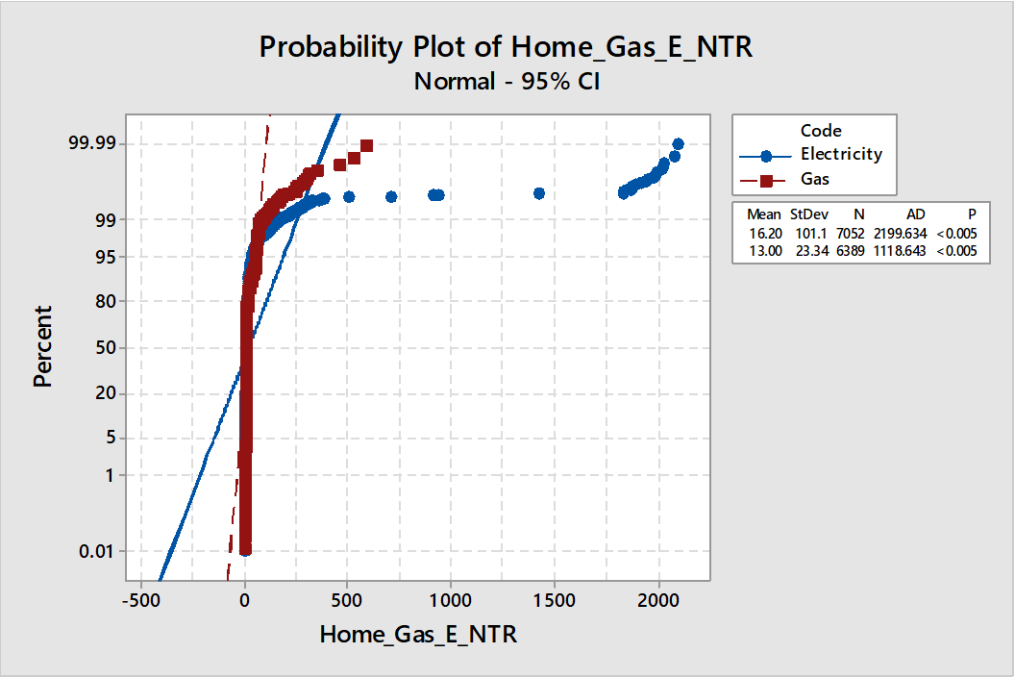
A6. Figure 30: Two sample t-test output for time spent at houses using gas stove compared to houses using electricity stove located near quiet roads – BC

Mann-Whitney Test and CI: Gas, Electricity

```
                N   Median
Gas          6886  0.68900
Electricity  8142  0.70800


Point estimate for η1 - η2 is -0.02300
95.0 Percent CI for η1 - η2 is (-0.04299,-0.00201)
W = 51178950.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0327
The test is significant at 0.0327 (adjusted for ties)
```

A6. Figure 31: Mann Whitney test output for time spent at houses using gas stove compared to houses using electricity stove located near quiet roads – BC



A6. Figure 32: Probability Plot for time spent at houses using gas stove compared to houses using electricity stove located near quiet roads – $PM_{2.5}$

Two-Sample T-Test and CI: Home_Gas_E_NTR, Code

```
Two-sample T for Home_Gas_E_NTR

Code           N  Mean  StDev  SE Mean
Electricity  7052    16    101      1.2
Gas          6389  13.0   23.3     0.29


Difference = μ (Electricity) - μ (Gas)
Estimate for difference:  3.20
95% CI for difference:  (0.78, 5.63)
T-Test of difference = 0 (vs ≠): T-Value = 2.59  P-Value = 0.010  DF = 7875
```

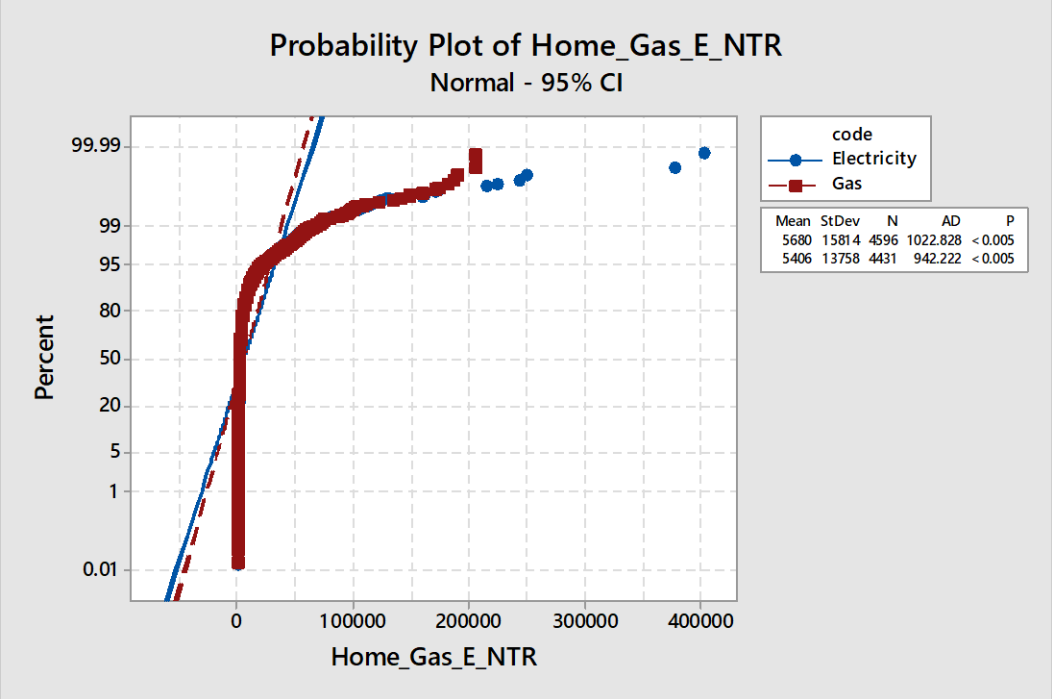
A6. Figure33: Two sample t-test output for time spent at houses using gas stove compared to houses using electricity stove located near quiet roads – $PM_{2.5}$

Mann-Whitney Test and CI: Home_Gas_NTR, Home_E_NTR

```
                  N  Median
Home_Gas_NTR   6389   6.380
Home_E_NTR     7052   6.292


Point estimate for η1 - η2 is 0.763
95.0 Percent CI for η1 - η2 is (0.602,0.926)
W = 45103909.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

A6. Figure 34: Mann Whitney test output for time spent at houses using gas stove compared to houses using electricity stove located a near quiet roads – $PM_{2.5}$



A6. Figure 35: Probability Plot for time spent at houses using gas stove compared to houses - UFP

Two-Sample T-Test and CI: Home_Gas_E_NTR, code

```
Two-sample T for Home_Gas_E_NTR

code            N  Mean  StDev  SE Mean
Electricity  4596  5680  15814      233
Gas          4431  5406  13758      207


Difference = μ (Electricity) - μ (Gas)
Estimate for difference:  274
95% CI for difference:  (-337, 885)
T-Test of difference = 0 (vs ≠): T-Value = 0.88  P-Value = 0.379  DF = 8931
```

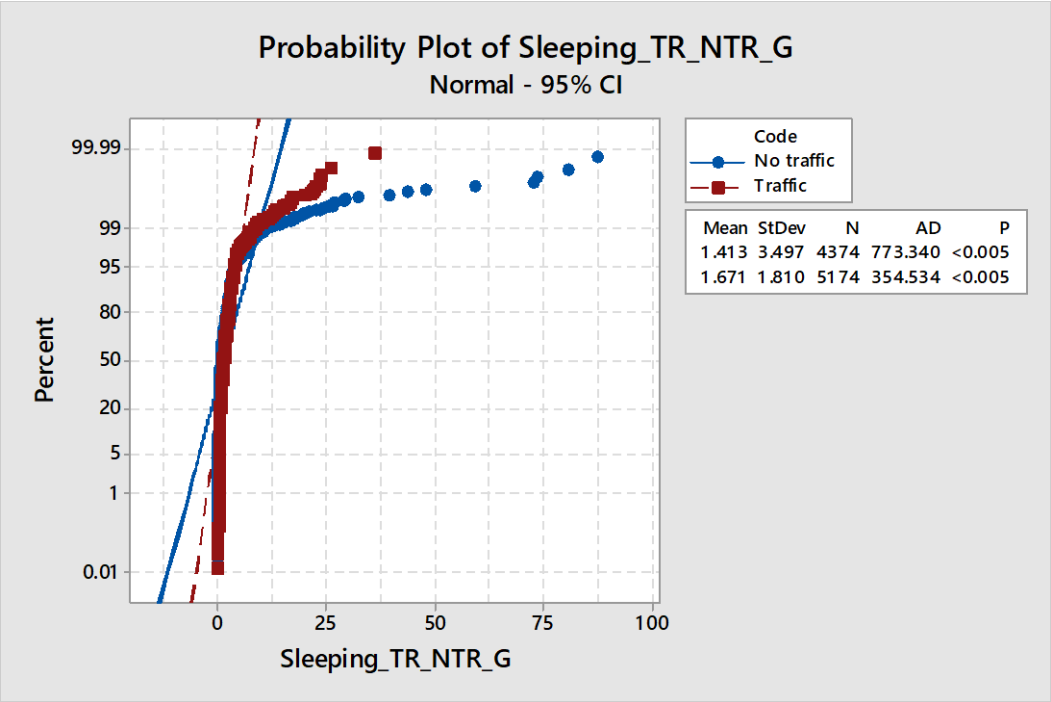
A6. Figure 36: Two sample t-test output for time spent at houses using gas stove compared to houses using electricity stove located near quiet roads – UFP

Mann-Whitney Test and CI: Home_Gas_E_NTR_Electricity, Home_Gas_E_NTR_Gas

```
                              N  Median
Home_Gas_E_NTR_Electricity  4596  2283.2
Home_Gas_E_NTR_Gas          4431  1904.9


Point estimate for η1 - η2 is 252.6
95.0 Percent CI for η1 - η2 is (182.8,323.0)
W = 21628527.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

A6. Figure 37: Mann Whitney test output for time spent at houses using gas stove compared to houses using electricity stove located near quiet roads – UFP



A6. Figure 38: Probability Plot for sleeping times in houses located near busy roads compared to houses located near quiet roads using gas stoves – BC

Two-Sample T-Test and CI: Sleeping_TR_NTR_G, Code

```
Two-sample T for Sleeping_TR_NTR_G

Code           N  Mean  StDev  SE Mean
No traffic  4374  1.41   3.50    0.053
Traffic     5174  1.67   1.81    0.025


Difference = μ (No traffic) - μ (Traffic)
Estimate for difference:  -0.2589
95% CI for difference:  (-0.3737, -0.1441)
T-Test of difference = 0 (vs ≠): T-Value = -4.42  P-Value = 0.000  DF = 6305
```

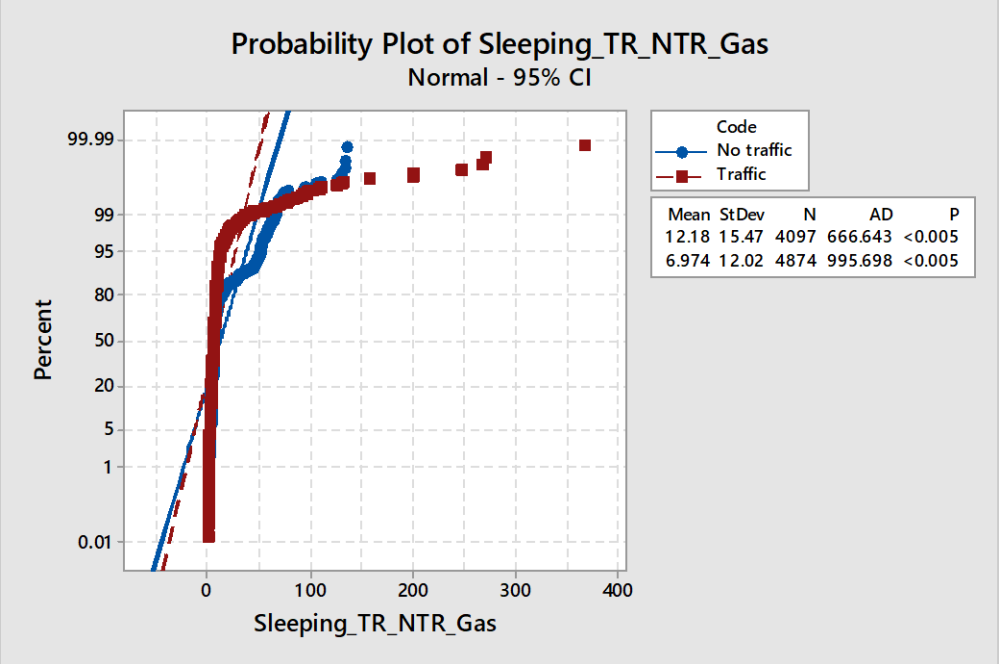
A6. Figure 39: Two sample t-test output for sleeping times in houses located near busy roads compared to houses located near quiet roads using gas stoves – BC

Mann-Whitney Test and CI: Sleeping_TR_NTR_, Sleeping_TR_NTR_

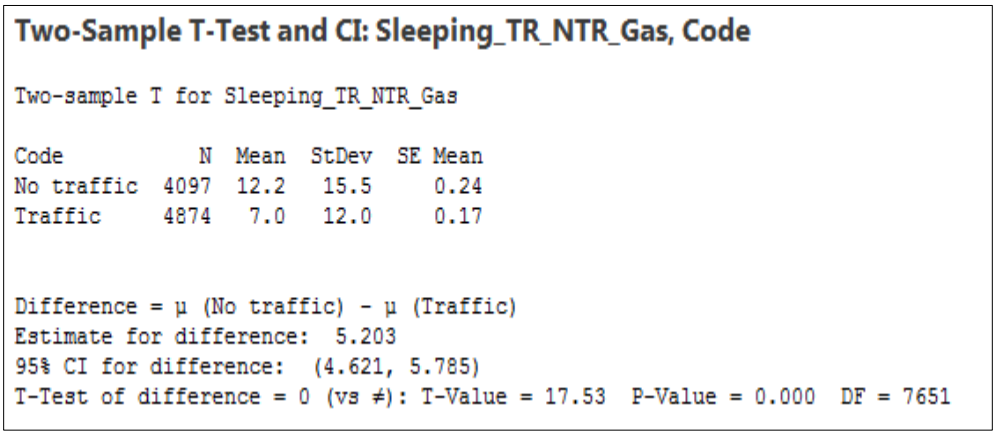
	N	Median
Sleeping_TR_NTR_G_No traffic	4374	0.6485
Sleeping_TR_NTR_G_Traffic	5174	1.3230

Point estimate for η1 - η2 is -0.4360
95.0 Percent CI for η1 - η2 is (-0.4720,-0.4000)
W = 17380805.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

A6. Figure 40: Mann Whitney test output for sleeping times in houses located near busy roads compared to houses located near quiet roads using gas stoves – BC



A6. Figure 41: Probability Plot for sleeping times in houses located busy roads compared to houses located near quiet roads using gas stoves – $PM_{2.5}$



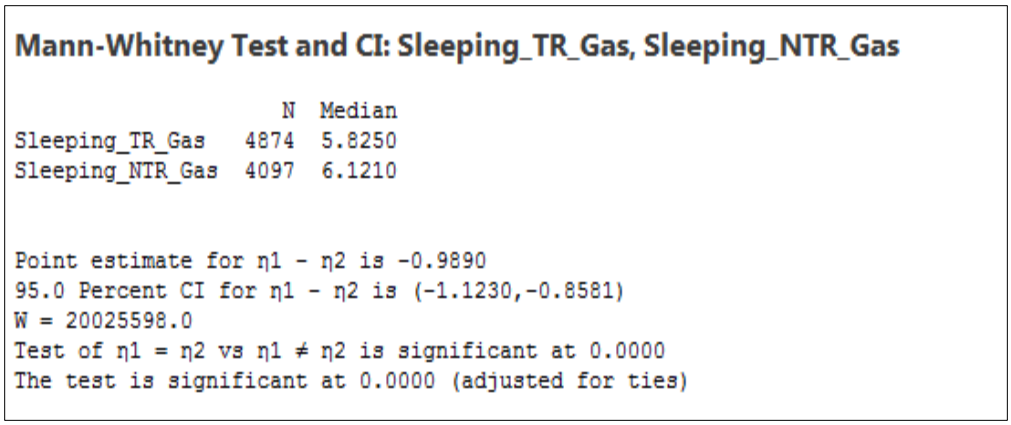
Two-Sample T-Test and CI: Sleeping_TR_NTR_Gas, Code

```
Two-sample T for Sleeping_TR_NTR_Gas

Code           N  Mean  StDev  SE Mean
No traffic  4097  12.2   15.5     0.24
Traffic     4874   7.0   12.0     0.17


Difference = μ (No traffic) - μ (Traffic)
Estimate for difference:  5.203
95% CI for difference:  (4.621, 5.785)
T-Test of difference = 0 (vs ≠): T-Value = 17.53  P-Value = 0.000  DF = 7651
```

A6. Figure 42: Two sample t-test output for sleeping times in houses located near busy roads compared to houses located near quiet roads using gas stoves – $PM_{2.5}$

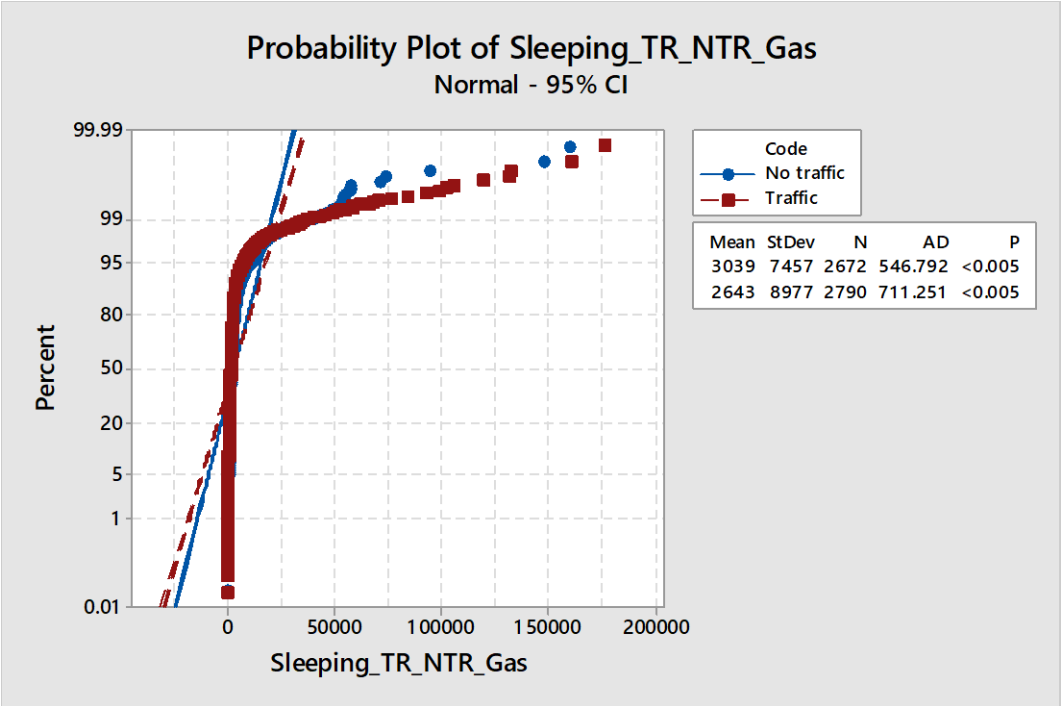


Mann-Whitney Test and CI: Sleeping_TR_Gas, Sleeping_NTR_Gas

```
                    N  Median
Sleeping_TR_Gas   4874  5.8250
Sleeping_NTR_Gas  4097  6.1210


Point estimate for η1 - η2 is -0.9890
95.0 Percent CI for η1 - η2 is (-1.1230,-0.8581)
W = 20025598.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

A6. Figure 43: Mann Whitney test output for sleeping times in houses located near busy roads compared to houses located near quiet roads using gas stoves – $PM_{2.5}$



A6. Figure 44: Probability Plot for sleeping times in houses located near busy roads compared to houses located near quiet roads using gas stoves – UFP

Two-Sample T-Test and CI: Sleeping_TR_NTR_Gas, Code

Two-sample T for Sleeping_TR_NTR_Gas

Code	N	Mean	StDev	SE Mean
No traffic	2672	3039	7457	144
Traffic	2790	2643	8977	170

Difference = μ (No traffic) - μ (Traffic)
Estimate for difference: 397
95% CI for difference: (-40, 834)
T-Test of difference = 0 (vs ≠): T-Value = 1.78 P-Value = 0.075 DF = 5353

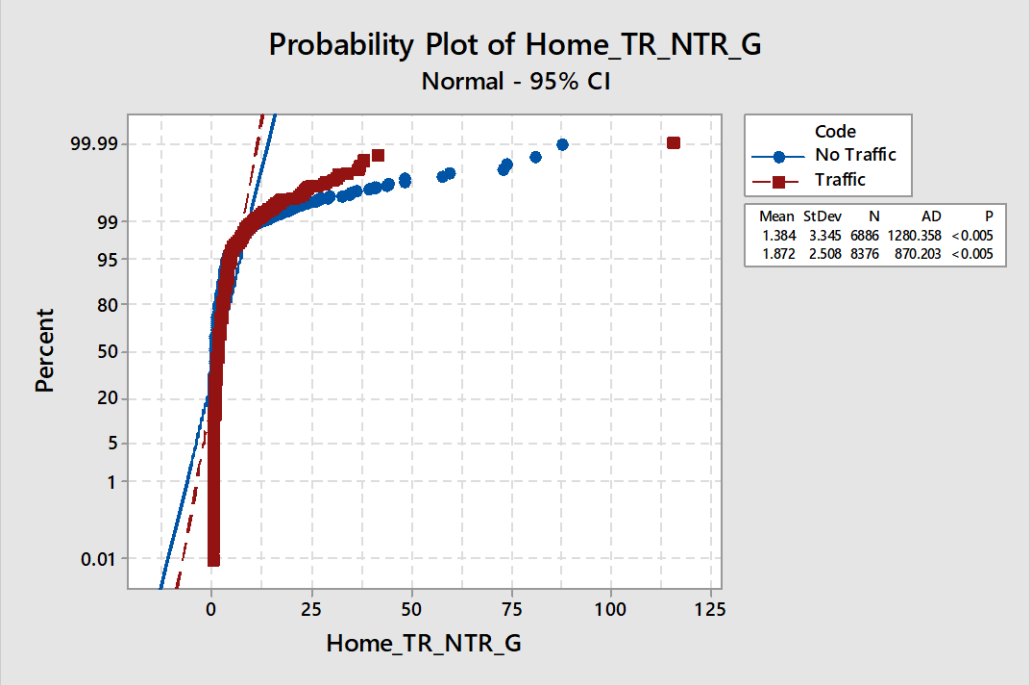
A6. Figure 45: Two sample t-test output for sleeping times in houses located near busy roads compared to houses located near quiet roads using gas stoves – UFP

Mann-Whitney Test and CI: Sleeping_TR_NTR_, Sleeping_TR_NTR_

	N	Median
Sleeping_TR_NTR_Gas_No traffic	2672	1407.6
Sleeping_TR_NTR_Gas_Traffic	2790	1209.5

Point estimate for η1 - η2 is 248.6
95.0 Percent CI for η1 - η2 is (193.0,306.5)
W = 7820099.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

A6. Figure 46: Mann Whitney test output for sleeping times in houses located near busy roads compared to houses located near quiet roads using gas stoves – UFP



A6. Figure 47: Probability Plot for time spent at houses located near busy roads compared to houses located near quiet roads using gas stoves – BC

Two-Sample T-Test and CI: Home_TR_NTR_G, Code

```
Two-sample T for Home_TR_NTR_G

Code           N  Mean  StDev  SE Mean
No Traffic  6886  1.38   3.35    0.040
Traffic     8376  1.87   2.51    0.027


Difference = μ (No Traffic) - μ (Traffic)
Estimate for difference:  -0.4880
95% CI for difference:  (-0.5835, -0.3924)
T-Test of difference = 0 (vs ≠): T-Value = -10.01  P-Value = 0.000  DF = 12519
```

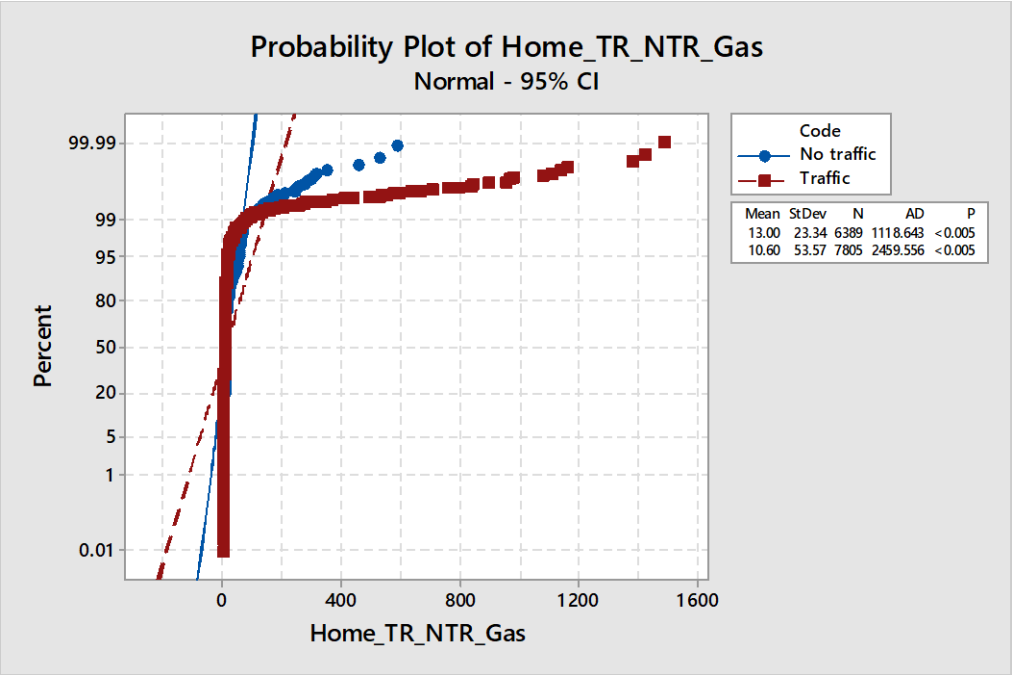
A6. Figure 48: Two sample t-test output for time spent at houses located near busy roads compared to houses located near quiet roads using gas stoves – BC

Mann-Whitney Test and CI: Home_TR_NTR_G_No Traffic, Home_TR_NTR_G_Traffic

```
                            N  Median
Home_TR_NTR_G_No Traffic  6886  0.6890
Home_TR_NTR_G_Traffic     8376  1.4345


Point estimate for η1 - η2 is -0.5470
95.0 Percent CI for η1 - η2 is (-0.5790,-0.5150)
W = 42257254.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

A6. Figure 49: Mann Whitney test output for time spent at houses located near busy roads compared to houses located near quiet roads using gas stoves – BC



A6. Figure 50: Probability Plot for time spent at houses located near busy roads compared to houses located near quiet roads using gas stoves – $PM_{2.5}$

Two-Sample T-Test and CI: Home_TR_NTR_Gas, Code

```
Two-sample T for Home_TR_NTR_Gas

Code           N  Mean  StDev  SE Mean
No traffic  6389  13.0   23.3     0.29
Traffic     7805  10.6   53.6     0.61


Difference = μ (No traffic) - μ (Traffic)
Estimate for difference:  2.394
95% CI for difference:  (1.074, 3.713)
T-Test of difference = 0 (vs ≠): T-Value = 3.56  P-Value = 0.000  DF = 11112
```

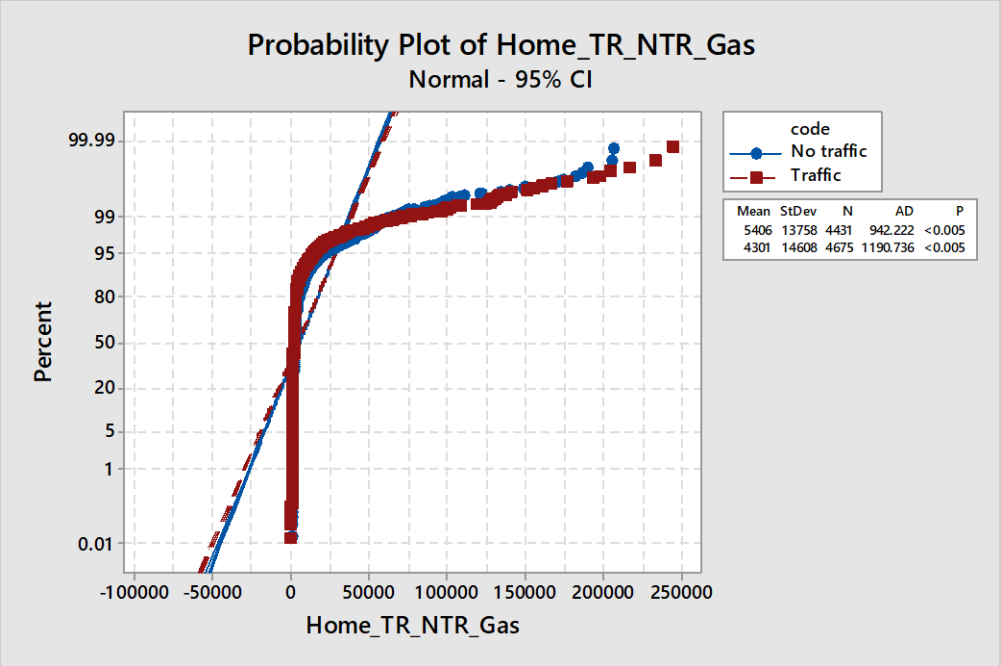
A6. Figure 51: Two sample t-test output for time spent at houses located near busy roads compared to houses located near quiet roads using gas stoves – $PM_{2.5}$

Mann-Whitney Test and CI: Home_TR_Gas, Home_NTR_Gas

	N	Median
Home_TR_Gas	7805	5.9970
Home_NTR_Gas	6389	6.3800

Point estimate for η1 - η2 is -1.0070
95.0 Percent CI for η1 - η2 is (-1.1230,-0.8920)
W = 51178929.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

A6. Figure 52: Mann Whitney test output for time spent at houses located near busy roads compared to houses located near quiet roads using gas stoves – $PM_{2.5}$



A6. Figure 53: Probability Plot for time spent at houses located near busy roads compared to houses located near quiet roads using gas stoves – UFP

Two-Sample T-Test and CI: Home_TR_NTR_Gas, code

```
Two-sample T for Home_TR_NTR_Gas

code           N  Mean  StDev  SE Mean
No traffic  4431  5406  13758      207
Traffic     4675  4301  14608      214


Difference = μ (No traffic) - μ (Traffic)
Estimate for difference:  1104
95% CI for difference:  (522, 1687)
T-Test of difference = 0 (vs ≠): T-Value = 3.72  P-Value = 0.000  DF = 9103
```

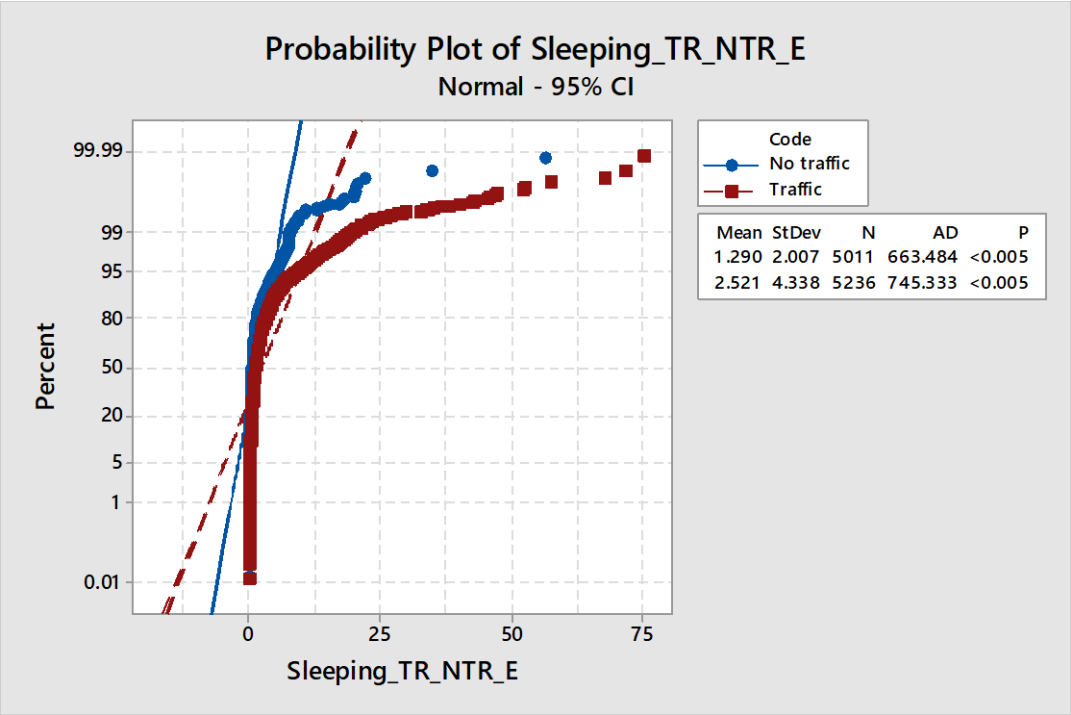
A6. Figure 54: Two sample t-test output for time spent at houses located near busy roads compared to houses located near quiet roads using gas stoves – UFP

Mann-Whitney Test and CI: Home_TR_Gas, Home_NTR_Gas

```
                 N  Median
Home_TR_Gas   4675  1445.3
Home_NTR_Gas  4431  1904.9


Point estimate for η1 - η2 is -468.3
95.0 Percent CI for η1 - η2 is (-528.1,-408.9)
W = 19286801.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

A6. Figure 55: Mann Whitney test output for time spent at houses located near busy roads compared to houses located near quiet roads using gas stoves – UFP



A6. Figure 56: Probability Plot for sleeping times in houses located near busy roads compared to houses located near quiet roads using electricity stoves – BC

Two-Sample T-Test and CI: Sleeping_TR_NTR_E, Code

```
Two-sample T for Sleeping_TR_NTR_E

Code           N  Mean  StDev  SE Mean
No traffic  5011  1.29   2.01    0.028
Traffic     5236  2.52   4.34    0.060


Difference = μ (No traffic) - μ (Traffic)
Estimate for difference:  -1.2308
95% CI for difference:  (-1.3608, -1.1008)
T-Test of difference = 0 (vs ≠): T-Value = -18.56  P-Value = 0.000  DF = 7450
```

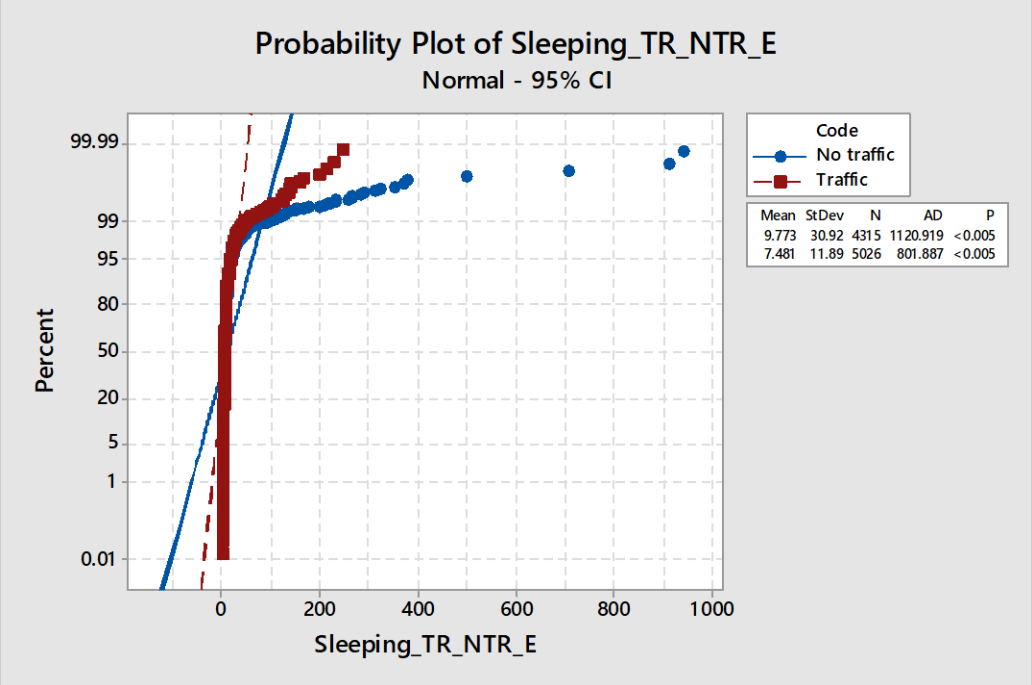
A6. Figure 57: Two sample t-test output for sleeping times in houses located near busy roads compared to houses located near quiet roads using electricity stoves – BC

Mann-Whitney Test and CI: Traffic, No_traffic

	N	Median
Traffic	5236	1.2480
No_traffic	5011	0.7020

Point estimate for η1 - η2 is 0.4590
95.0 Percent CI for η1 - η2 is (0.4220,0.4960)
W = 30905579.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

A6. Figure 58: Mann Whitney test output for sleeping times in houses located near busy roads compared to houses located near quiet roads using electricity stoves – BC



A6. Figure 59: Probability Plot for sleeping times in houses located near busy roads compared - $PM_{2.5}$

Two-Sample T-Test and CI: Sleeping_TR_NTR_E, Code

```
Two-sample T for Sleeping_TR_NTR_E

Code           N  Mean  StDev  SE Mean
No traffic  4315   9.8   30.9     0.47
Traffic     5026   7.5   11.9     0.17


Difference = μ (No traffic) - μ (Traffic)
Estimate for difference:  2.292
95% CI for difference:  (1.312, 3.272)
T-Test of difference = 0 (vs ≠): T-Value = 4.59  P-Value = 0.000  DF = 5403
```

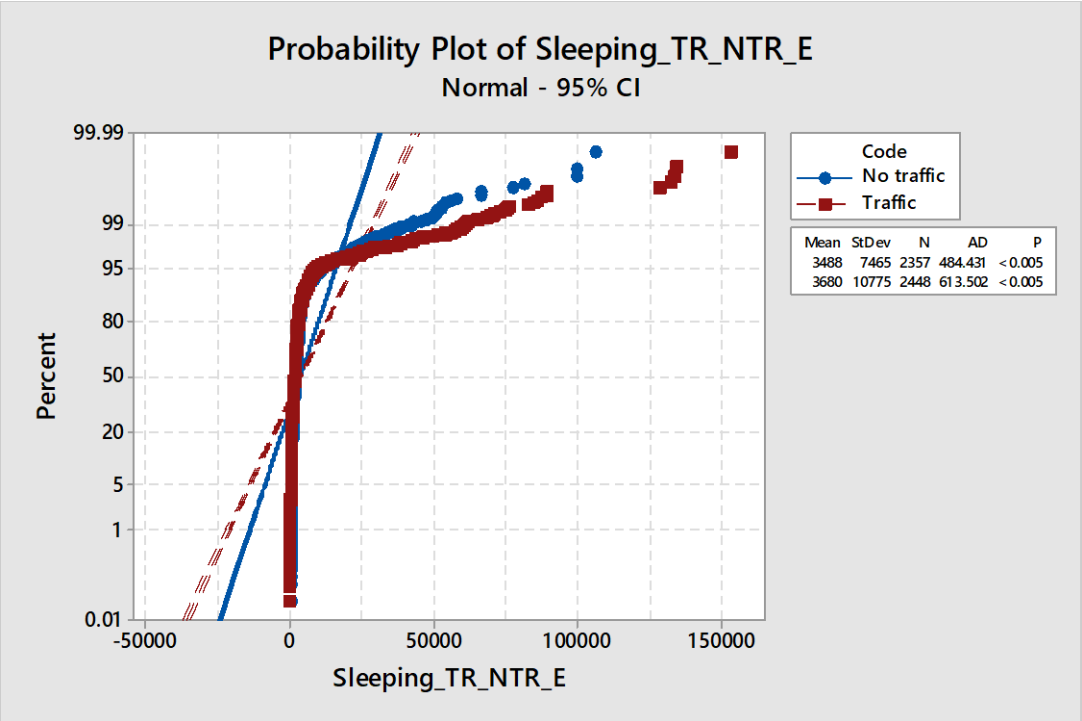
A6. Figure 60: Two sample t-test output for sleeping times in houses located near busy roads compared to houses located near quiet roads using electricity stoves – $PM_{2.5}$

Mann-Whitney Test and CI: Sleeping_TR_E, Sleeping_NTR_E

```
                  N  Median
Sleeping_TR_E   5026  5.3975
Sleeping_NTR_E  4315  6.2120


Point estimate for η1 - η2 is -0.7690
95.0 Percent CI for η1 - η2 is (-0.9090,-0.6249)
W = 22109282.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

A6. Figure 61: Mann Whitney test output for sleeping times in houses located near busy roads compared to houses located near quiet roads using electricity stoves – $PM_{2.5}$



A6. Figure 62: Probability Plot for sleeping times in houses located near busy roads compared to houses located near quiet roads using electricity stoves – UFP

Two-Sample T-Test and CI: Sleeping_TR_NTR_E, Code

```
Two-sample T for Sleeping_TR_NTR_E

Code           N  Mean  StDev  SE Mean
No traffic  2357  3488   7465      154
Traffic     2448  3680  10775      218


Difference = μ (No traffic) - μ (Traffic)
Estimate for difference:  -193
95% CI for difference:  (-715, 330)
T-Test of difference = 0 (vs ≠): T-Value = -0.72  P-Value = 0.470  DF = 4367
```

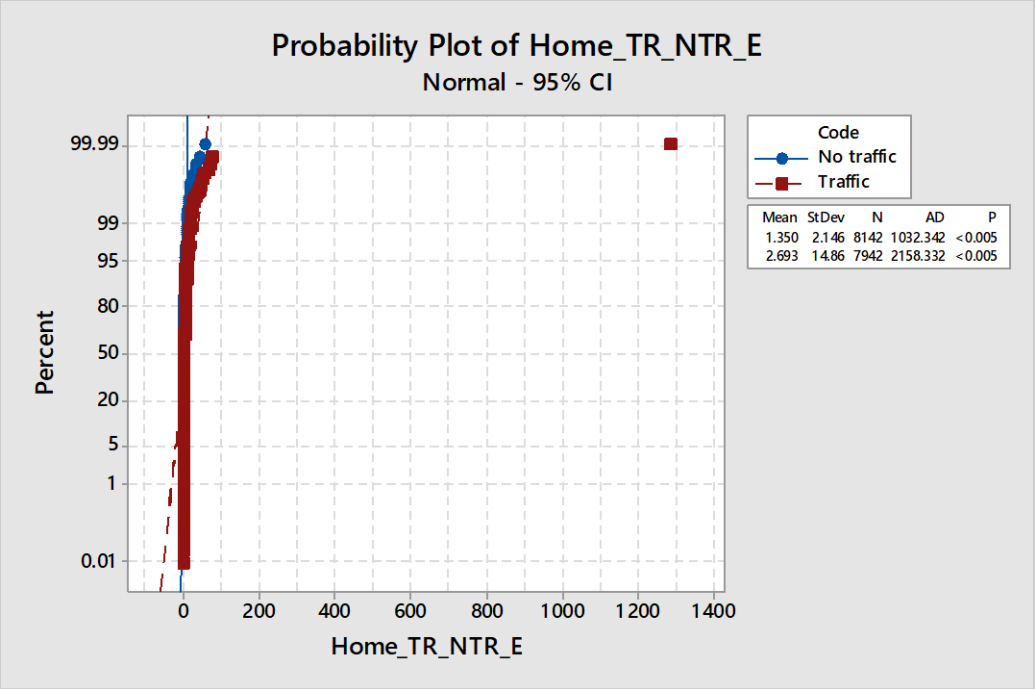
A6. Figure 63: Two sample t-test output for sleeping times in houses located near busy roads compared to houses located near quiet roads using electricity stoves – UFP

Mann-Whitney Test and CI: Sleeping_TR_E, Sleeping_NTR_E

	N	Median
Sleeping_TR_E	2448	1558.6
Sleeping_NTR_E	2357	1854.4

Point estimate for η1 - η2 is -310.1
95.0 Percent CI for η1 - η2 is (-382.1,-239.6)
W = 5473670.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

A6. Figure 64: Mann Whitney test output for sleeping times in houses located near busy roads compared to houses located near quiet roads using electricity stoves – UFP



A6. Figure 65: Probability Plot for time spent at houses located near busy roads compared to houses located near quiet roads using electrical stoves – BC

Two-Sample T-Test and CI: Home_TR_NTR_E, Code

```
Two-sample T for Home_TR_NTR_E

Code           N  Mean  StDev  SE Mean
No traffic  8142  1.35   2.15    0.024
Traffic     7942   2.7   14.9     0.17


Difference = μ (No traffic) - μ (Traffic)
Estimate for difference:  -1.343
95% CI for difference:  (-1.673, -1.013)
T-Test of difference = 0 (vs ≠): T-Value = -7.97  P-Value = 0.000  DF = 8263
```

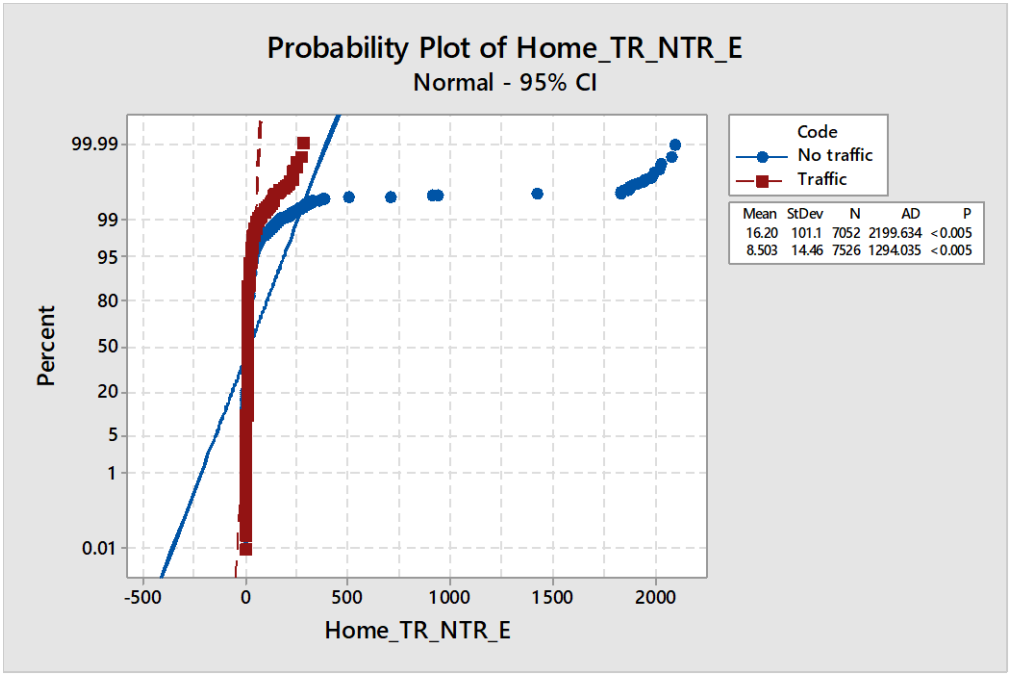
A6. Figure 66: Two sample t-test output for time spent at houses located near busy roads compared to houses located near quiet roads using electrical stoves – BC

Mann-Whitney Test and CI: Traffic, No_Traffic

```
               N  Median
Traffic     7942  1.5330
No_Traffic  8142  0.7080


Point estimate for η1 - η2 is 0.6410
95.0 Percent CI for η1 - η2 is (0.6082,0.6741)
W = 75972762.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

A6. Figure 67: Mann Whitney test output for time spent at houses located near busy roads compared to houses located near quiet roads using electrical stoves – BC



A6. Figure 68: Probability Plot for time spent at houses located near busy roads compared to houses located near quiet roads using electrical stoves – $PM_{2.5}$

Two-Sample T-Test and CI: Home_TR_NTR_E, Code

```
Two-sample T for Home_TR_NTR_E

Code           N  Mean  StDev  SE Mean
No traffic  7052    16    101      1.2
Traffic     7526   8.5   14.5     0.17


Difference = μ (No traffic) - μ (Traffic)
Estimate for difference:  7.70
95% CI for difference:  (5.32, 10.08)
T-Test of difference = 0 (vs ≠): T-Value = 6.34  P-Value = 0.000  DF = 7321
```

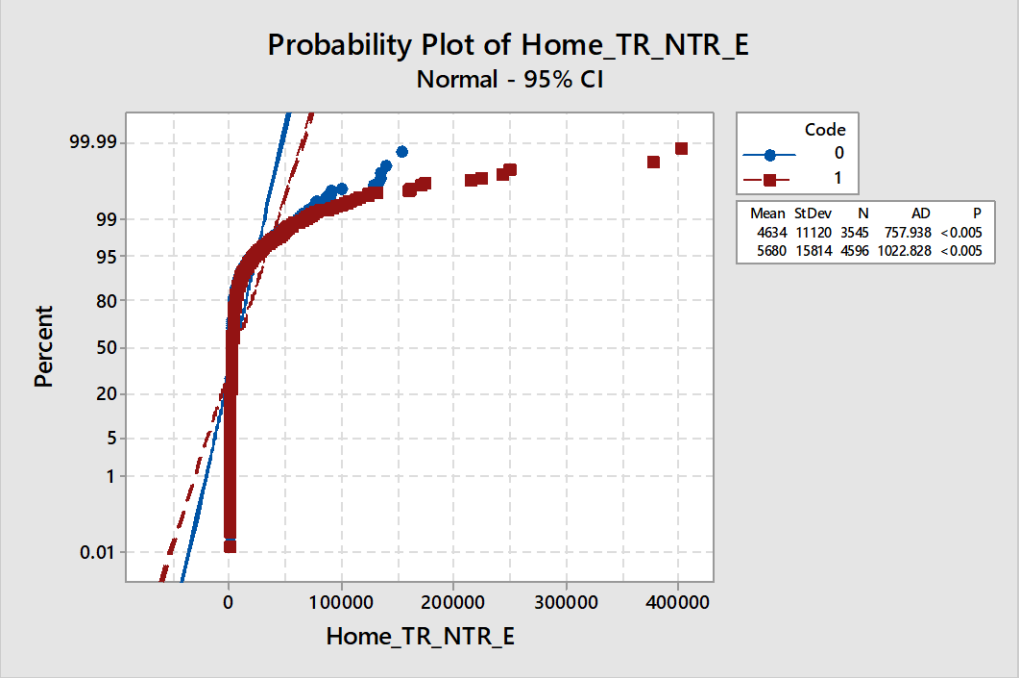
A6. Figure 69: Two sample t-test output for time spent at houses located near busy roads compared to houses located near quiet roads using electrical stoves – $PM_{2.5}$

Mann-Whitney Test and CI: Home_TR_E, Home_NTR_E

	N	Median
Home_TR_E	7526	5.770
Home_NTR_E	7052	6.292

Point estimate for η1 − η2 is −0.327
95.0 Percent CI for η1 − η2 is (−0.465,−0.189)
W = 53679805.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

A6. Figure 70: Mann Whitney test output for time spent at houses located near busy roads compared to houses located near quiet roads using electrical stoves – $PM_{2.5}$



A6. Figure 71: Probability Plot for time spent at houses located near busy roads compared to houses located near quiet roads using electrical stoves – UFP

Two-Sample T-Test and CI: Home_TR_NTR_E, Code

```
Two-sample T for Home_TR_NTR_E

Code     N  Mean  StDev  SE Mean
0     3545  4634  11120      187
1     4596  5680  15814      233


Difference = μ (0) - μ (1)
Estimate for difference:  -1046
95% CI for difference:  (-1632, -460)
T-Test of difference = 0 (vs ≠): T-Value = -3.50  P-Value = 0.000  DF = 8073
```

A6. Figure 72: Two sample t-test output for time spent at houses located near busy roads compared to houses located near quiet roads using electrical stoves – UFP

Mann-Whitney Test and CI: Home_TR_E, Home_NTR_E

```
               N  Median
Home_TR_E   3545  1801.7
Home_NTR_E  4596  2283.2


Point estimate for η1 - η2 is -419.5
95.0 Percent CI for η1 - η2 is (-490.8,-348.9)
W = 13203797.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

A6. Figure 73: Mann Whitney test output for time spent at houses located near busy roads compared to houses located near quiet roads using electrical stoves – UFP

Appendix 7

Forms and materials

UNIVERSITY OF BIRMINGHAM

School of Geography, Earth and Environmental Sciences

PARTICIPANTS NEEDED FOR AIR POLLUTION

RESEARCH PROJECT

Do you….

Have you thought about how can pollutants produced from candle

Are you….

- **Non-smoker?**
- **Healthy adult?**
- **English Speaker?**

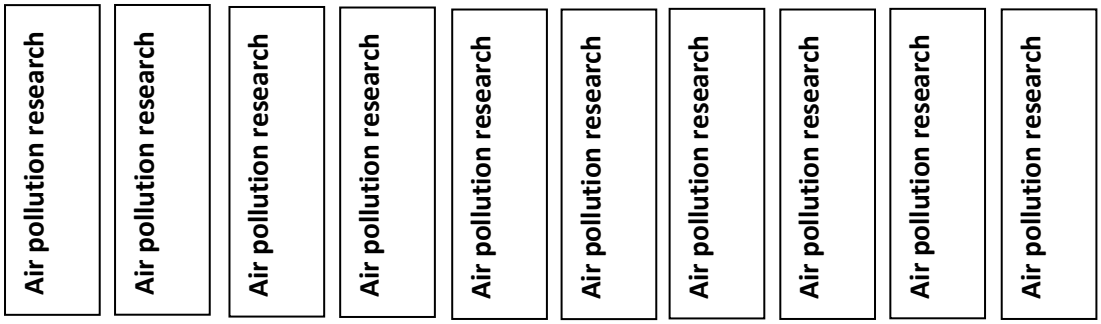
We are seeking to recruit volunteers to take part in a research project investigating the human personal exposures to airborne pollutants and its effect to cognitive performance
A reward of £30 will be given for the participants to thank you for volunteering

If you are interested, please contact Ms Maryam Shehab

( )

Announcement for volunteers needed through my.bham portal

ANNOUNCEMENT: Are you non-smoker, Healthy adult and first language English? We are seeking to recruit volunteers to take part in a research project investigating the human personal exposures to airborne pollutants and its effect to cognitive performance. A reward of £30 will be given for the participants to thank you for volunteering. If you are interested, please contact Ms Maryam Shehab ( )



PARTICIPANT INFORMATION SHEET

HEI Project – Effects of air pollution on cognitive performance

The purpose of this information sheet is to provide background to our research project and to explain what will be asked of you if you agree to enrol as a participant.

Background

Epidemiological studies have found evidence of adverse effects on cognitive performance associated with air pollution in children. However, there have been very few studies performed on healthy adults. Some activities which cause air pollution exposure to humans, such as lighting candles, may affect human cognitive performance, such as memory and attention. The research will explore the relationship between short term particulate matter air pollution emitted from candles and cognitive performance (i.e. memory, attention). The research will assess if short-term particulate matter exposure has an effect on memory, attention and physical cognition.

Your involvement

Our study is not evaluating your health. It is concerned with measuring your exposure to particulate matter emitted from a regular candle, and the effect of the particulate matter on your cognitive performance (memory, attention and physical cognition). In order to do this, we are recruiting healthy non-smoking volunteers from the general public. Volunteers should be native English speakers. Those who complete the study will each be paid £30 as compensation for any inconvenience which the study may cause them. Each volunteer will be examined twice, pre-exposure and post-exposure to particulate matter. Each session will take around 40 minutes which includes questionnaire filling. Cognitive test are three paper tests. Volunteers will also be asked to fill the following questionnaire:

- Consent form
- Confounding questionnaire
- Screening questionnaire

Anonymous and confidential results

Each participant will be assigned a random ID code. The results of the measurements will be anonymised. This will be known only to the researcher and the Principal Investigator. The information linking the participant identities and ID codes will be kept in a secure locked cabinet.

Further questions / actions

If after reading this participant information sheet you have any questions, please contact researcher Maryam Shehab using the following details. Once you are entirely happy in participating in the study, please sign the attached consent form and return it to a member of our research team

in the enclosed pre-paid envelope. A meeting will be organised between the researcher and the participant for further questions before proceeding with the sampling.

Contact details:
Lead supervisor: Dr. Francis Pope
[redacted]
Doctoral researcher: Maryam Shehab
E-mail: [redacted]

Withdrawing from the project

If after giving your consent to participate in the project, you want to withdraw and don't want to do the test, you can do so three days before the test day, and during three weeks after the test day, withdrawal after three weeks will not be accepted. To do so, you just need to contact myself at [redacted] and express your wish to withdraw from the study. We will then remove all your details from our database according to your wish.

Maryam Shehab

Doctoral researcher

ID CODE

For researcher use only:

UNIVERSITY OF BIRMINGHAM

Assessment of human exposures to airborne pollutants and its effects to cognitive performance

Screening Questionnaire

1- Is English your first language?

☐ Yes
☐ No

2- What is your postcode? ----------

3- Have you ever had brain surgery?
☐ Yes
☐ No

4- Have you ever had a brain injury?
☐ Yes
☐ No

5- Have you ever had an accident that affected your mental condition/ function and required you to visit the emergency room (ER)?
☐ Yes
☐ No

If yes, please specify what kind of accident (Car accident, work accident, bullet,

assault...etc.)

6- Are you taking prescribed medication for any mental condition/ functions right now? (e.g. Memory problems, attention problems, judgment, recollection..etc.)

☐ Yes
☐ No

If yes, please describe the mental condition for which it has been prescribed,

and what, if any are its side effects

Condition: ----------

Side effects: ----------

7- Have you ever been diagnosed with any of the following? (Circle all that apply)

☐ Depression
☐ Anxiety
☐ Schizophrenia
☐ Dementia
☐ Attention deficit disorder
☐ Fatigue
☐ Multiple sclerosis (MS)
☐ Brain cancer
☐ Brain tumour
☐ Other: ----------

8- Are you currently experiencing any of the following problems? (Circle all that apply):

☐ Colour blindness
☐ Headaches

☐ Ringing in the ears
☐ Dizziness
☐ Irritability
☐ Memory problems
☐ Sleep problems
☐ Concentration
☐ Difficulty Problem Solving
☐ Emotional changes
☐ Changes in your relationships with others
☐ Balance problems
☐ Difficulty with reading, writing, calculating
☐ Poor Judgment
☐ Other: ----------

Researcher use only

ID Code:

CONCENT FORM

HEI Project – Effects of air pollution on cognitive performance

I have read and understood the Participant Information Sheet provided to me with this Consent Form. Any outstanding questions have been answered satisfactorily by the research team. I agree to participate in the study by allowing measurements of air pollutant concentrations to be made in the sampling room and filling the corresponding information sheets, and tested for cognitive performance, using the tests provided.

I confirm that I have been informed that I will be tested for cognitive performance using tests including Stroop Colour Test, Ruff 2&7, and Mini-Mental Status Examination. I have been informed that the room will contain lighting candles to measure particulate matter. I have been informed that I will repeat the test before and after lighting the candles. I therefore agree to participate in this study.

As a minor compensation for any inconvenience caused, I will be receiving a sum of £30 upon completion of one sampling period.

I have been informed of my right to withdraw at anytime, even if I sign this consent form.

NAME OF VOLUNTEER SUBJECT:

.....

SIGNATURE: .....

DATE: .....

NAME OF RESEARCHER:

.....

SIGNATURE: .....

DATE: .....

NAME OF WITNESS:

.....

SIGNATURE: .....

DATE: .....

Researcher use only

ID Code

WITHDRAWAL FORM

HEI Project – Effects of air pollution on cognitive performance

I no longer wish to participate in the HEI Project and I would like that the following information is deleted from the database of the study:

Information provided in questionnaires:

- ☐ Screening Questionnaire Information
- ☐ Consent form

Information provided by the samplers:

- ☐ Exposure concentrations
- ☐ Tests results

NAME OF VOLUNTEER SUBJECT:

.....

SIGNATURE: .....

DATE: .....

For researcher use only:

ID CODE

UNIVERSITY OF BIRMINGHAM

Assessment of human exposures to airborne pollutants and its effects to cognitive performance

Part one: Noise exposure

- General information about noise in your everyday life

1. Are you exposed to loud noise...

... at your current home?	... at your current workplace?
☐ Yes	☐ Yes
☐ No	☐ No

If yes, please describe the source(s) of that noise and the amount of time you are exposed each day

Source:

Average hours per day: ----------

Average times per month: ----------

Time: ☐ Day ☐ Evening

2. Do you regularly engage in noisy hobbies (e.g.: use of motorcycles, power tools, or loud music?

☐ Yes

☐ No

If yes, please describe:

3. Does the noise affect your sleep?

☐ Yes

☐ No

4. In which way does the noise affect your health?

- <u>Information about noise in the 24-h prior to taking the test</u>

5. Were you exposed to loud noise...

a) ... at your current home? b) ... at your current workplace? C)… somewhere else?

☐ Yes	☐ Yes	☐ Yes
☐ No	☐ No	☐ No

If yes, please describe the source(s) of that noise and the amount of time you were exposed in the 24-h prior to taking the test

Source:

6. Did the noise affect your sleep last night?

☐ Yes

☐ No

Part two: Sleeping questions

7. In general, do you have trouble ...

a) ... getting asleep? b) ... staying asleep?

☐ Yes	☐ Yes
☐ No	☐ No

8. Last night, did you have trouble...

a) ... getting asleep?
☐ Yes

☐ No

b) ... staying asleep?
☐ Yes

☐ No

9. Do you usually wake up feeling refreshed on weekdays?

☐ Yes

☐ No

10. Did you wake up feeling refreshed this morning?

☐ Yes

☐ No

11. Do you feel you have a problem of any sort with your sleep?

☐ Yes

☐ No

If yes, please describe the problem:

12. How satisfied are you with the amount of sleep you get?

a) In general:

☐ Dissatisfied ☐ Fair ☐ Satisfied

b) Last night:

☐ Dissatisfied ☐ Fair ☐ Satisfied

13. Overall how would you rate the quality of your sleep?

a) In general:

☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good ☐Excellent

a) Last night:

☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good ☐Excellent

Part three: Emotional State

Please indicate how often each problem has bothered you during the past month and in the previous

24-h. Mark one of the boxes to the left that best corresponds to your problems:

14. Feelings of sadness

a) In general:

☐ Not at all ☐ Seldom ☐ Sometimes ☐ Often ☐ All the time

b) During the last 24-h:

☐ Not at all ☐ Seldom ☐ Sometimes ☐ Often ☐ All the time

15. Feeling easily irritated or annoyed

a) In general:

☐ Not at all ☐ Seldom ☐ Sometimes ☐ Often ☐ All the time

b) During the last 24-h:
☐ Not at all ☐ Seldom ☐ Sometimes ☐ Often ☐ All the time

16. Tension or inability to relax

a) In general:
☐ Not at all ☐ Seldom ☐ Sometimes ☐ Often ☐ All the time

b) During the last 24-h:
☐ Not at all ☐ Seldom ☐ Sometimes ☐ Often ☐ All the time

17. Diminished ability to think or concentrate

a) In general:
☐ Not at all ☐ Seldom ☐ Sometimes ☐ Often ☐ All the time

b) During the last 24-h:
☐ Not at all ☐ Seldom ☐ Sometimes ☐ Often ☐ All the time

18. Fatigue or loss of energy

a) In general:
☐ Not at all ☐ Seldom ☐ Sometimes ☐ Often ☐ All the time

b) During the last 24-h:
☐ Not at all ☐ Seldom ☐ Sometimes ☐ Often ☐ All the time

Part four: General information about you

19.Gender

☐ Male ☐ Female

20. Age group

☐ Under 24 years old

☐ 25-35 years old

☐ 36-45 years old

☐ 46-55 years old

☐ Over 56 years old

21. What is your weight? ----------

22. What is your height? ----------

23. What is the highest degree or level of school you have completed? If currently enrolled, highest degree received

☐ Secondary school

☐ High school

☐ Diploma/technical qualification

☐ UG degree/professional qualification

☐ PG degree

24. What is your present occupational position or (if no longer working) your last position?

☐ Higher managerial, administrative and professional occupations

☐ Intermediate occupations

☐ Routine and manual occupations

☐ Never worked and long-term unemployed

☐ Student

25. What is your job title?

Part five: Caffeine consumption:

26. Do you generally consume caffeinated products? (e.g. tea, coffee, energy drinks, soft drinks, chocolate. etc.)

☐ Yes ☐ No

27. When was the last time you had caffeine? ----------

Part six: Health status:

28. Are you currently experiencing any of the following problems in the last 24 hours? (Circle all that apply):

☐ Headaches
☐ Ringing in the ears
☐ Dizziness
☐ Irritability
☐ Memory problems
☐ Sleep problems
☐ Concentration
☐ Difficulty Problem Solving
☐ Emotional changes
☐ Changes in your relationships with others
☐ Balance problems

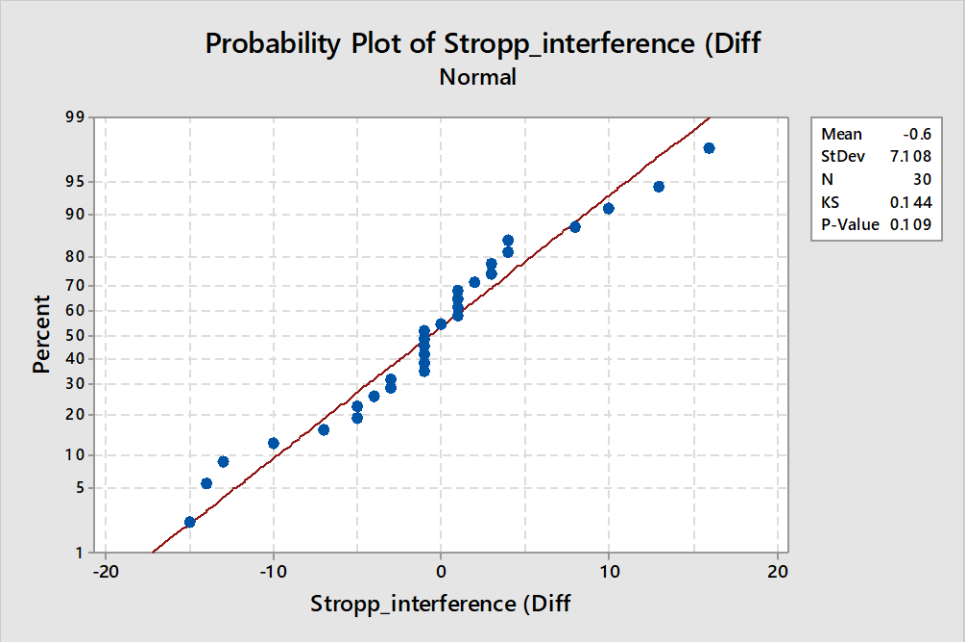
☐ Difficulty with reading, writing, calculating
☐ Poor Judgment
☐ Other: ----------

Appendix 8

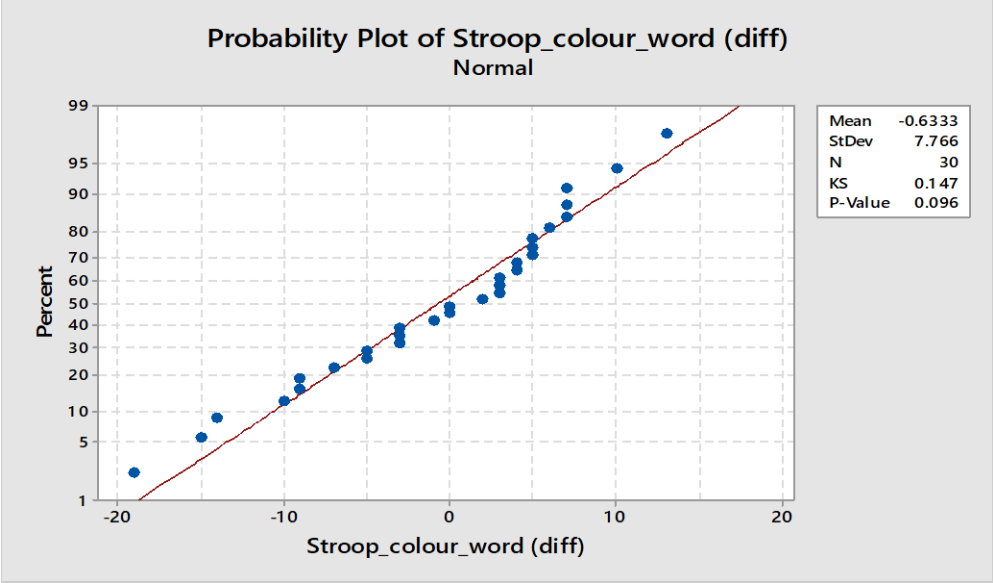
Outputs for chapter 6 results

Kolmogorov-Smirnov Outputs

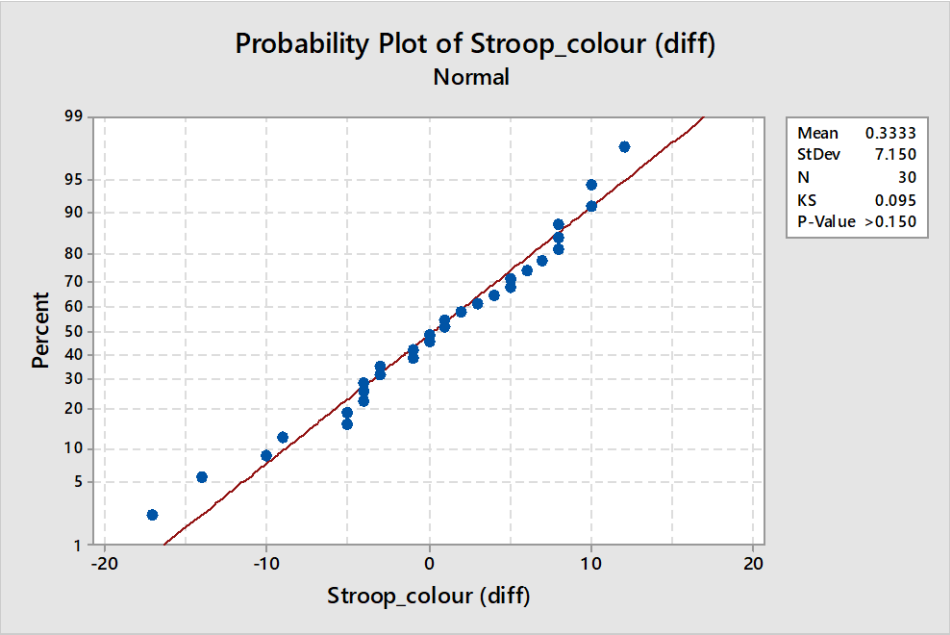
Candle Project (MMSE, Stroop, Ruff)



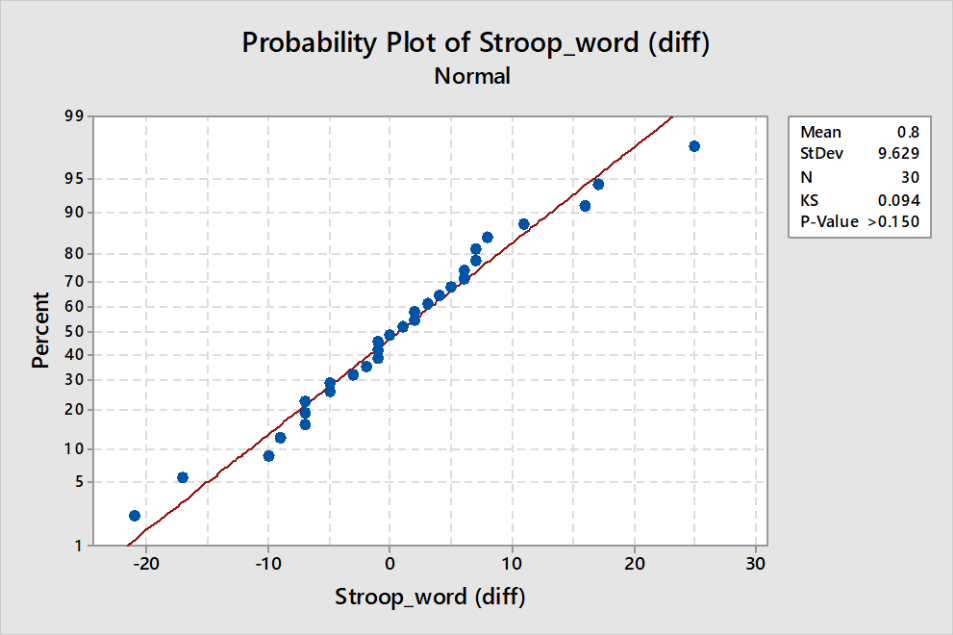
A8. Figure 1: Stroop interference probability plot



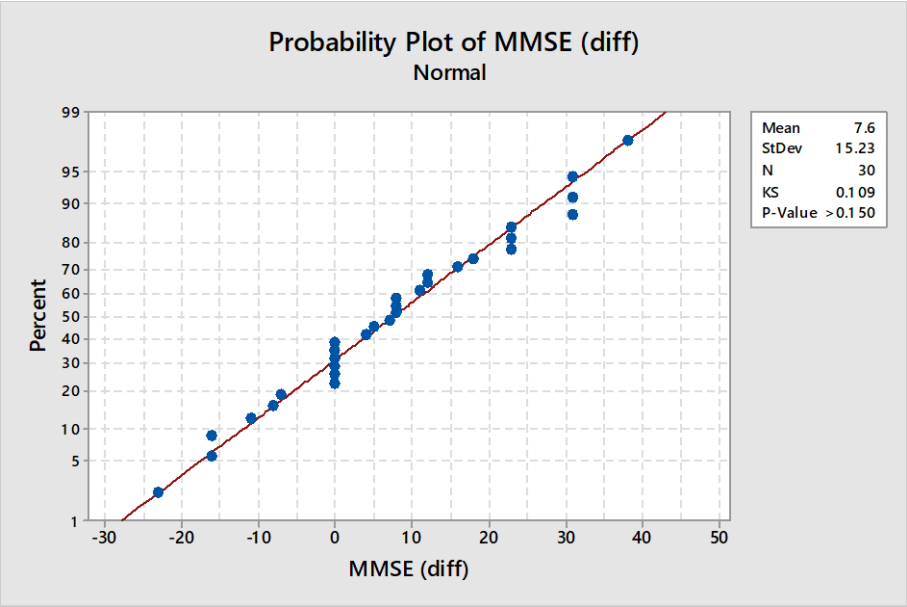
A8. Figure 2: Stroop Color-Word probability plot



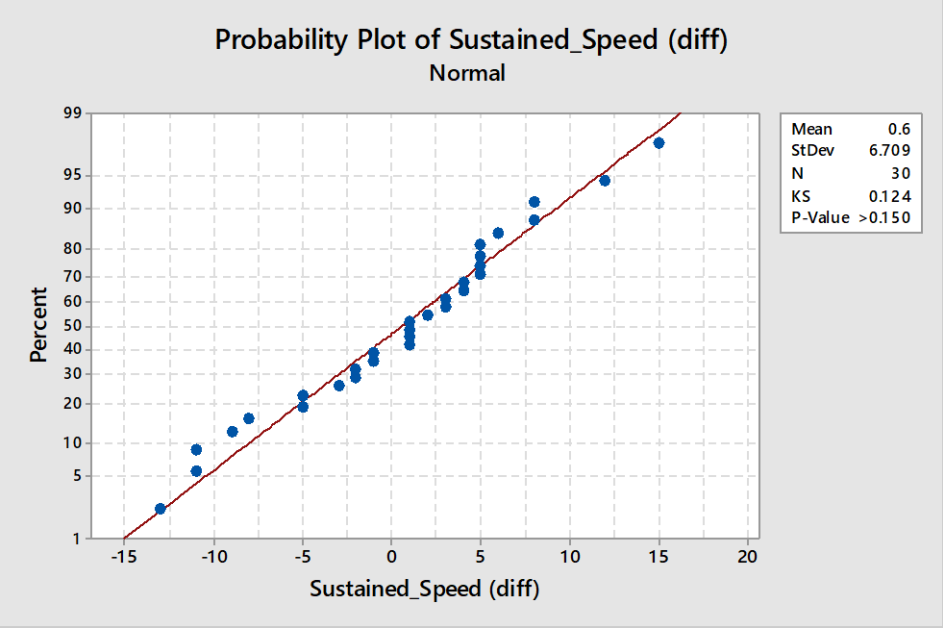
A8. Figure 3: Stroop Color probability plot



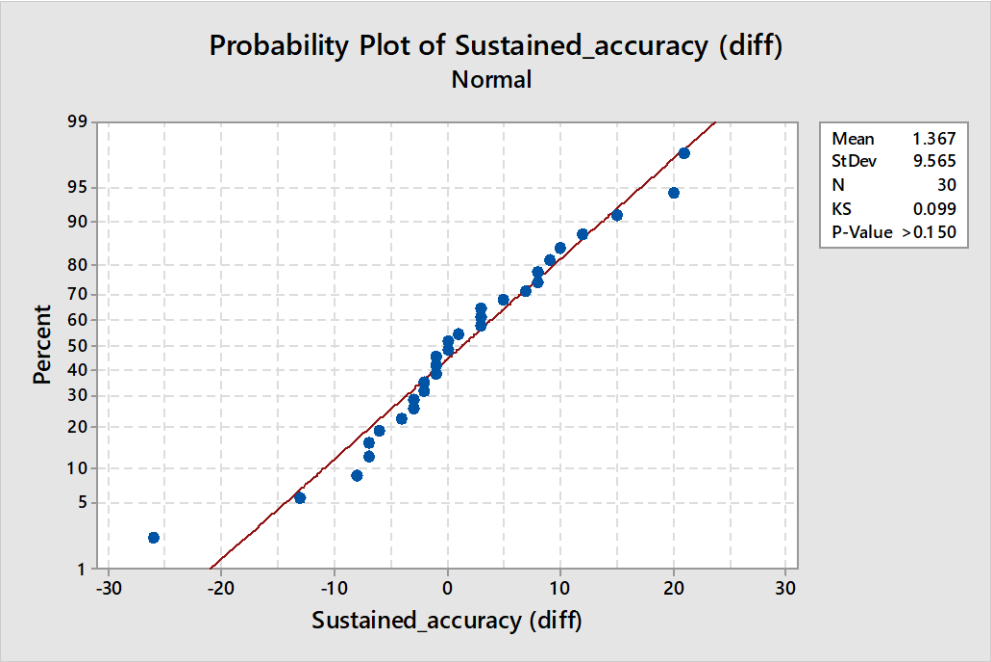
A8. Figure 4: Stroop Word probability plot



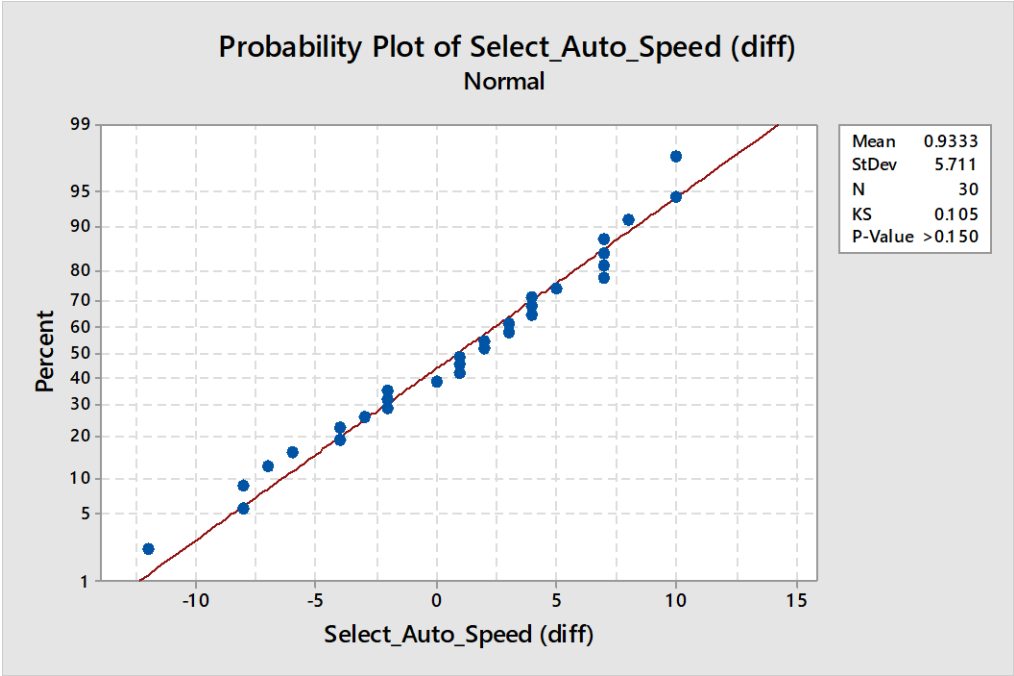
A8. Figure 5: MMSE probability plot



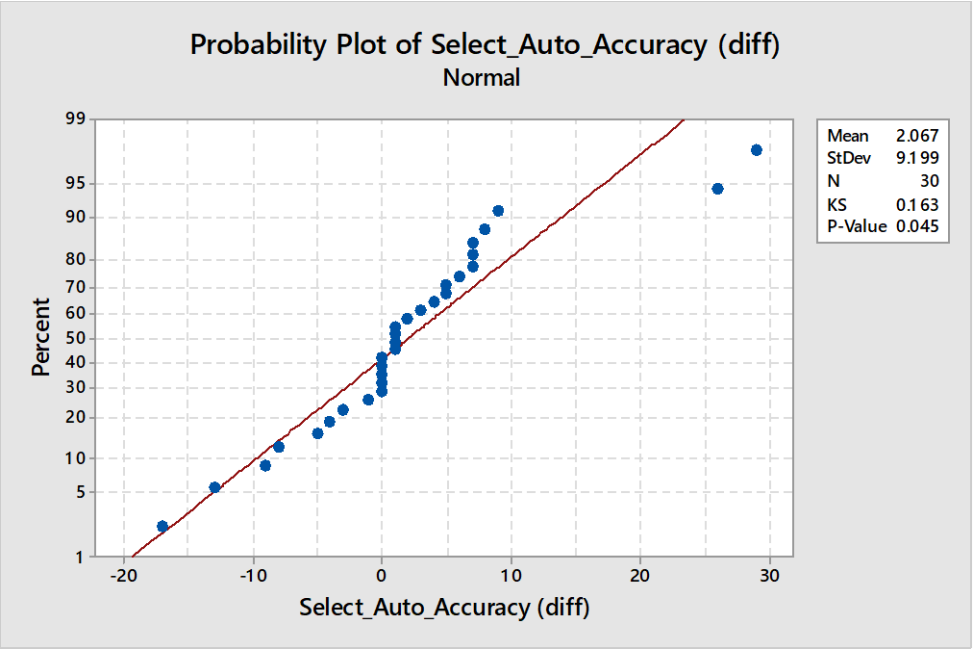
A8. Figure 6: sustained attention – speed probability plot



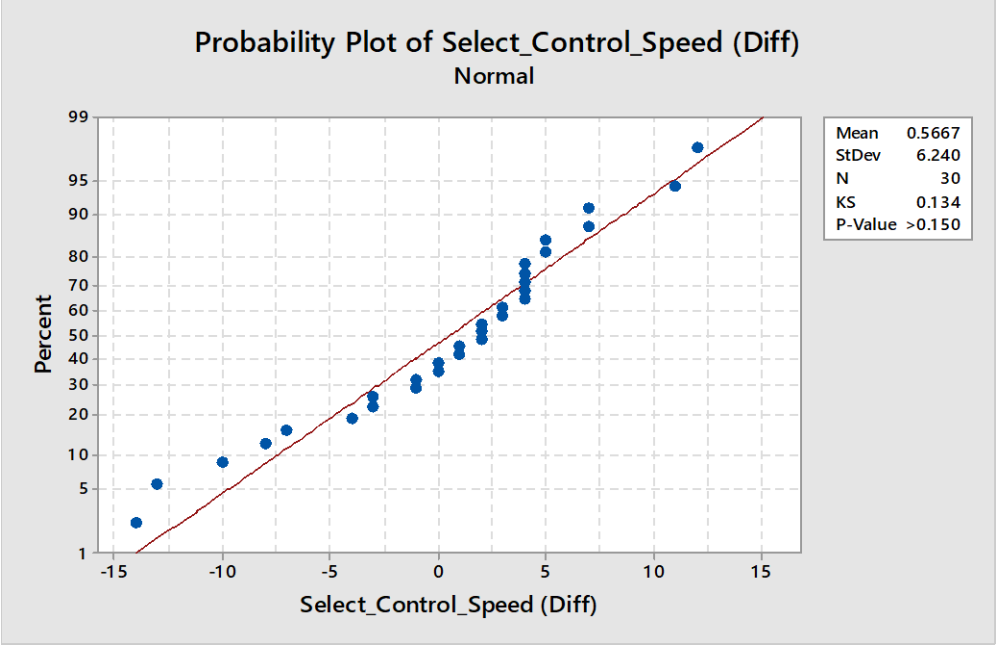
A8. Figure 7: sustained attention – accuracy probability plot



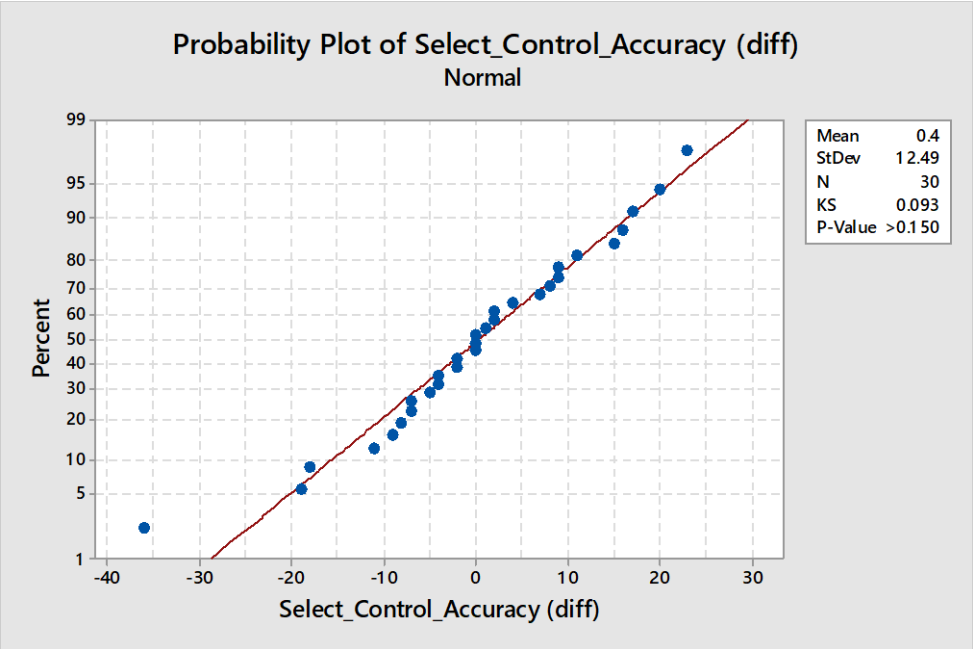
A8. Figure 8: selective attention - automatic detection speed probability plot



A8. Figure 9: selective attention - automatic detection accuracy probability plot

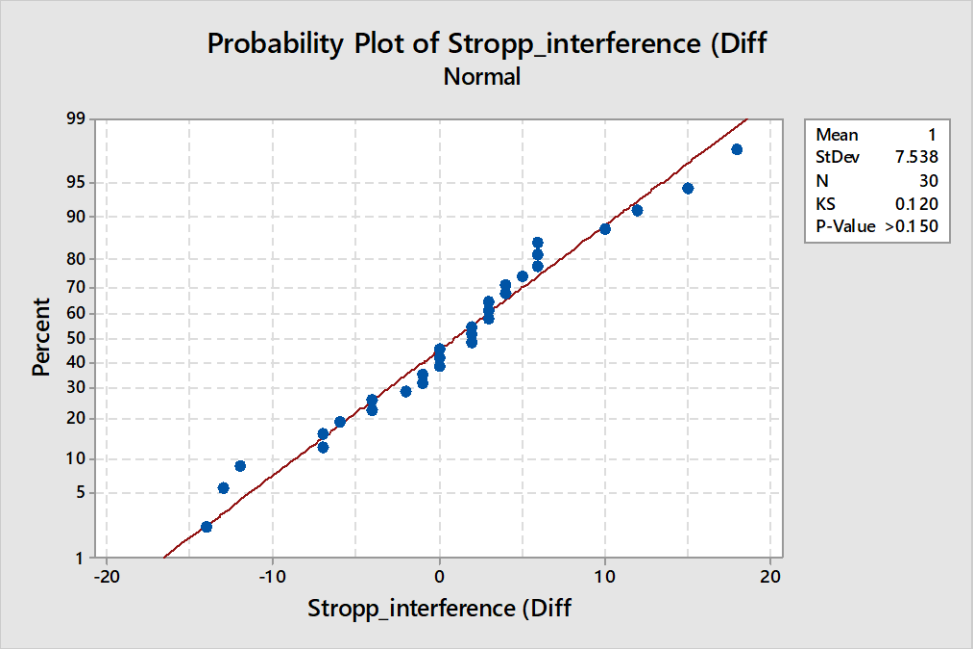


A8. Figure 10: selective attention - controlled search speed probability plot

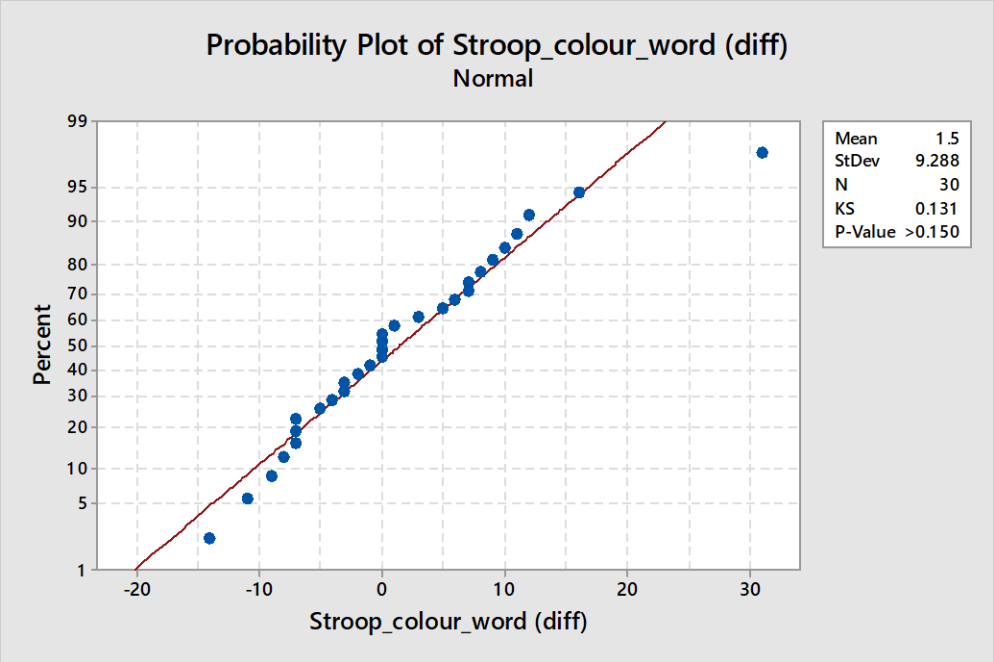


A8. Figure 11: selective attention - controlled search accuracy probability plot

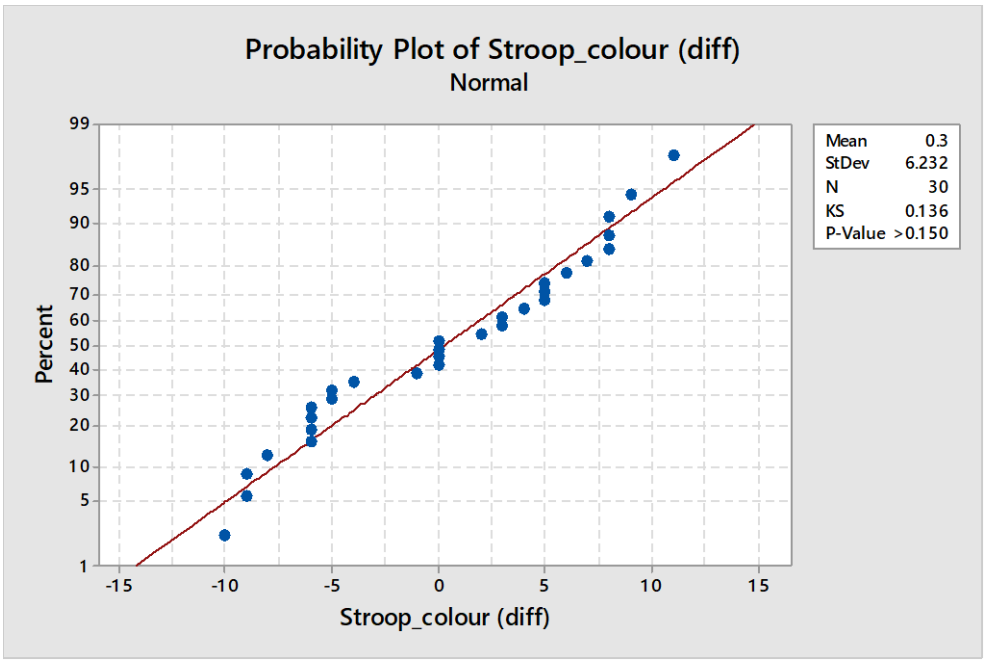
Commuting project (MMSE, Stroop, Ruff)



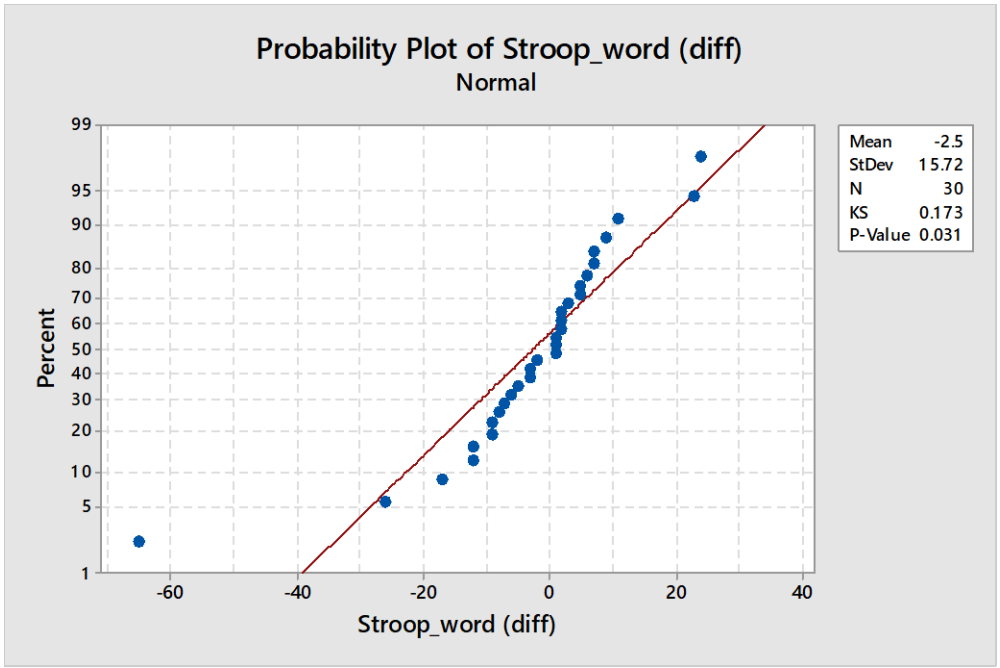
A8. Figure 12: Stroop interference probability plot - commuting



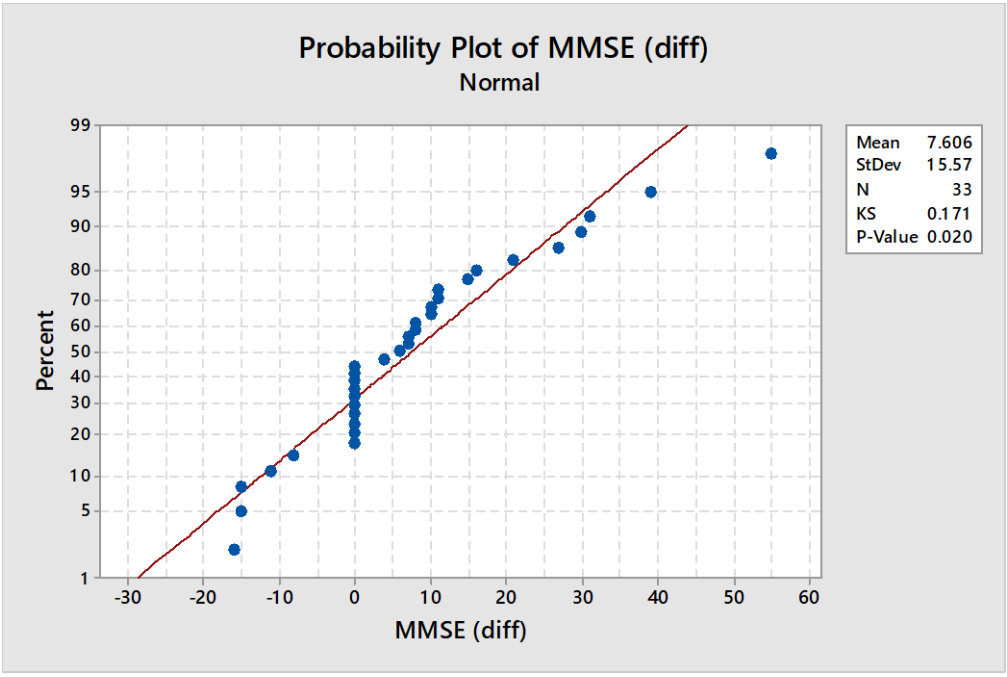
A8. Figure 13: Stroop Color-Word probability plot - commuting



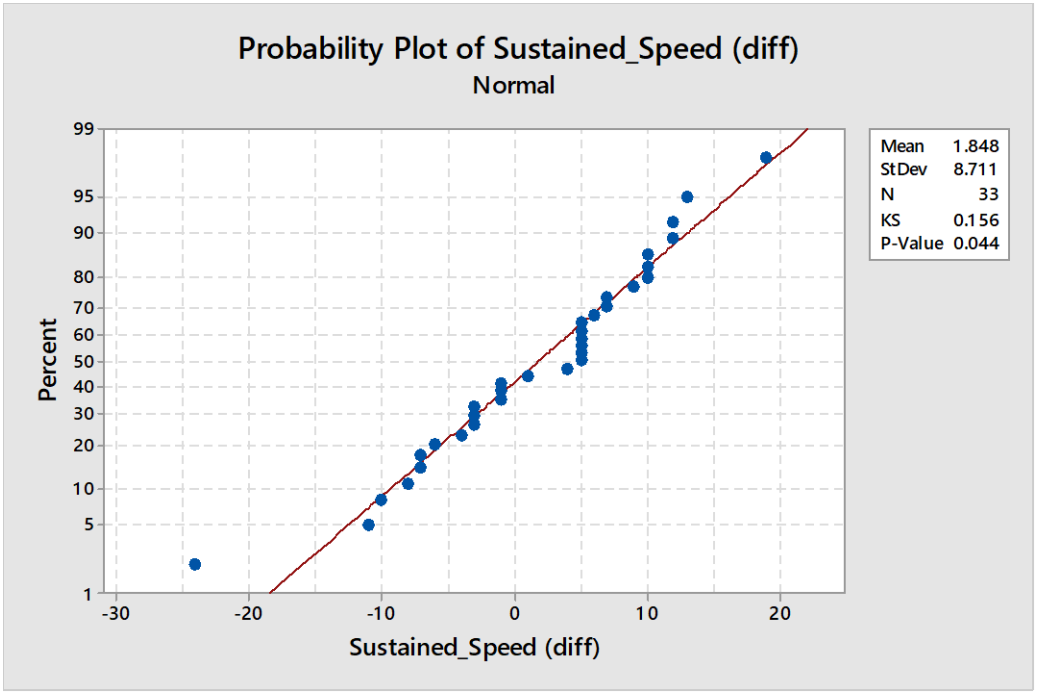
A8. Figure 14: Stroop Color probability plot - commuting



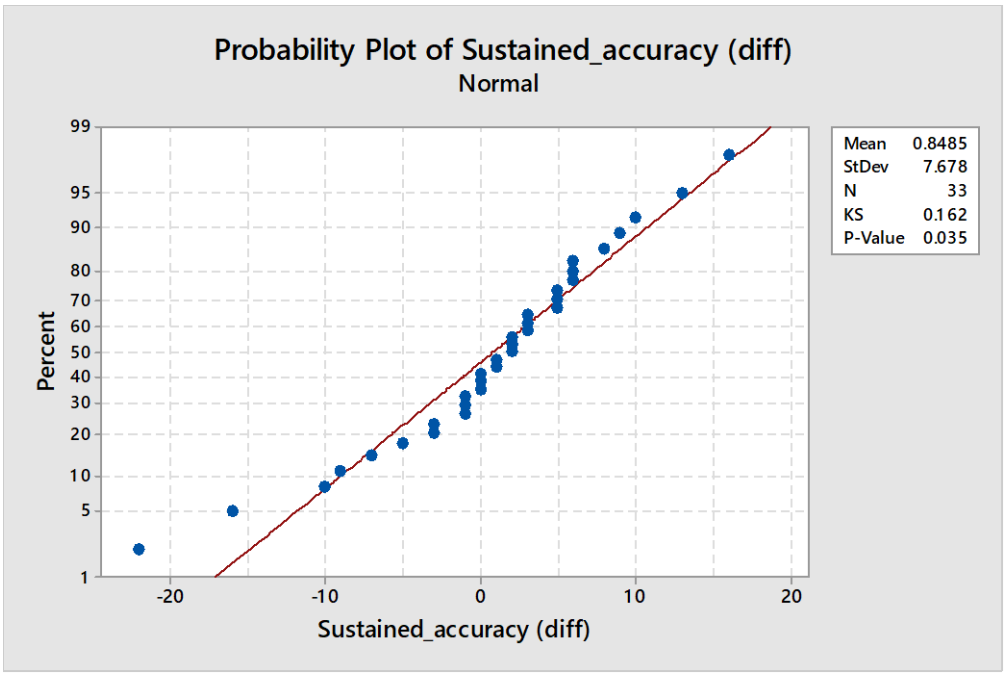
A8. Figure 15: Stroop Word probability plot - commuting



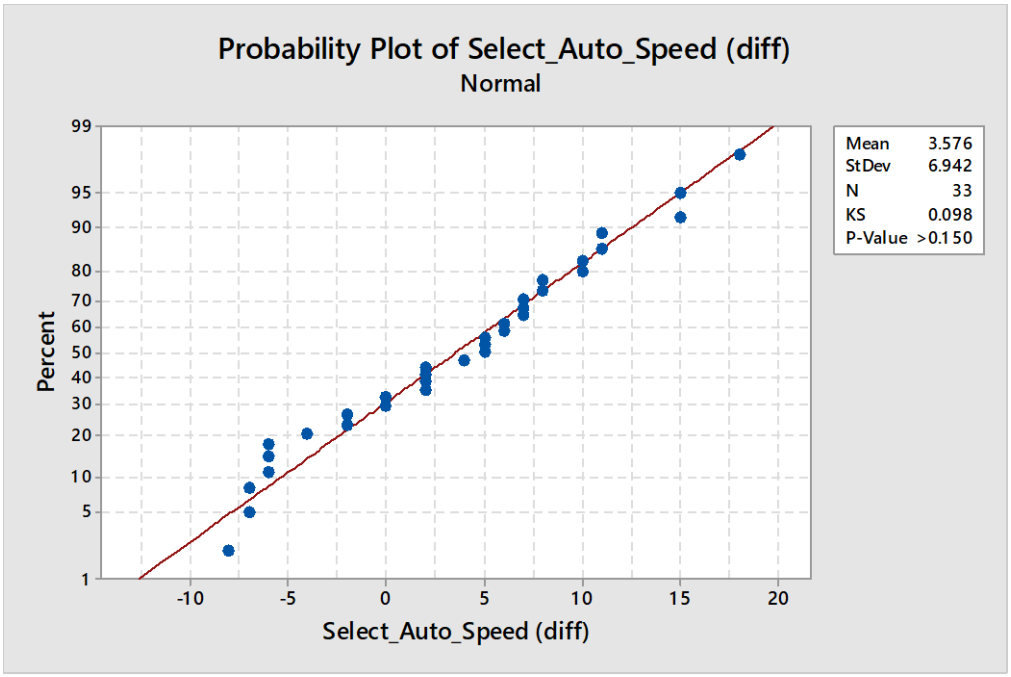
A8. Figure 16: MMSE probability plot - commuting



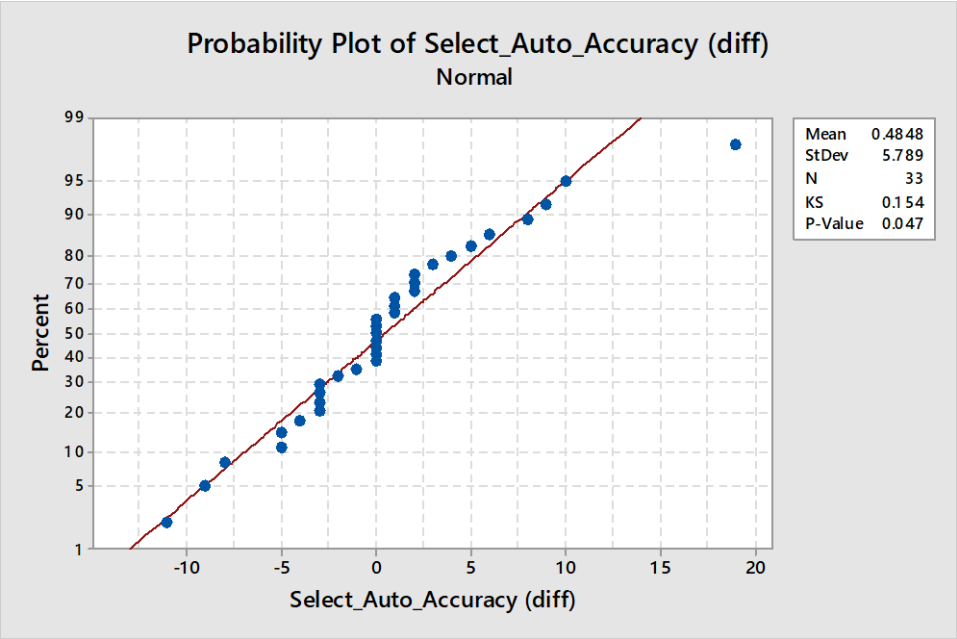
A8. Figure 17: sustained attention – speed probability plot - commuting



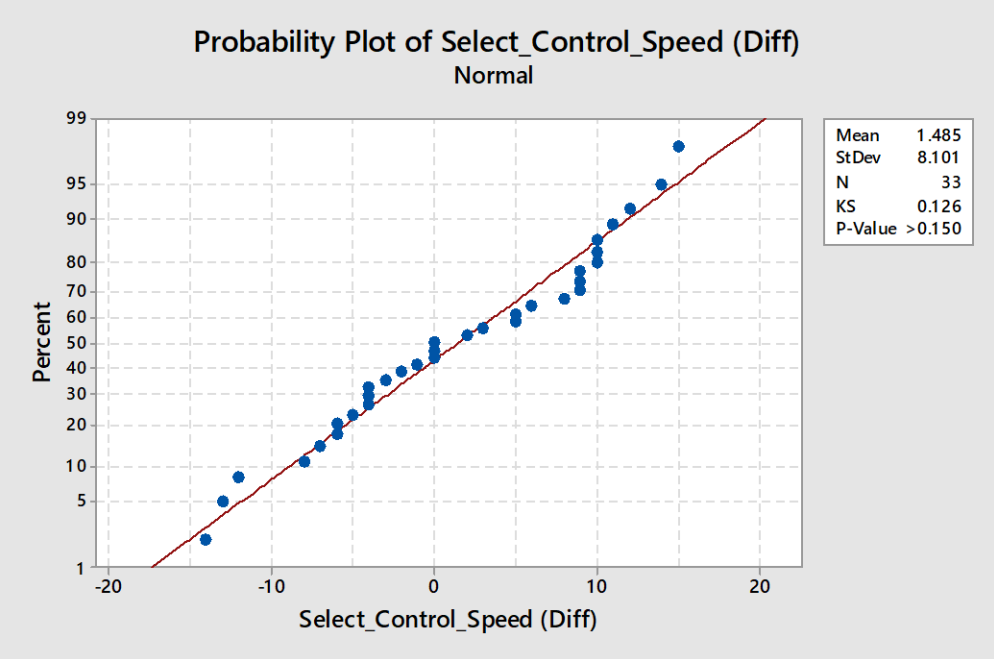
A8. Figure 18: sustained attention – accuracy probability plot - commuting



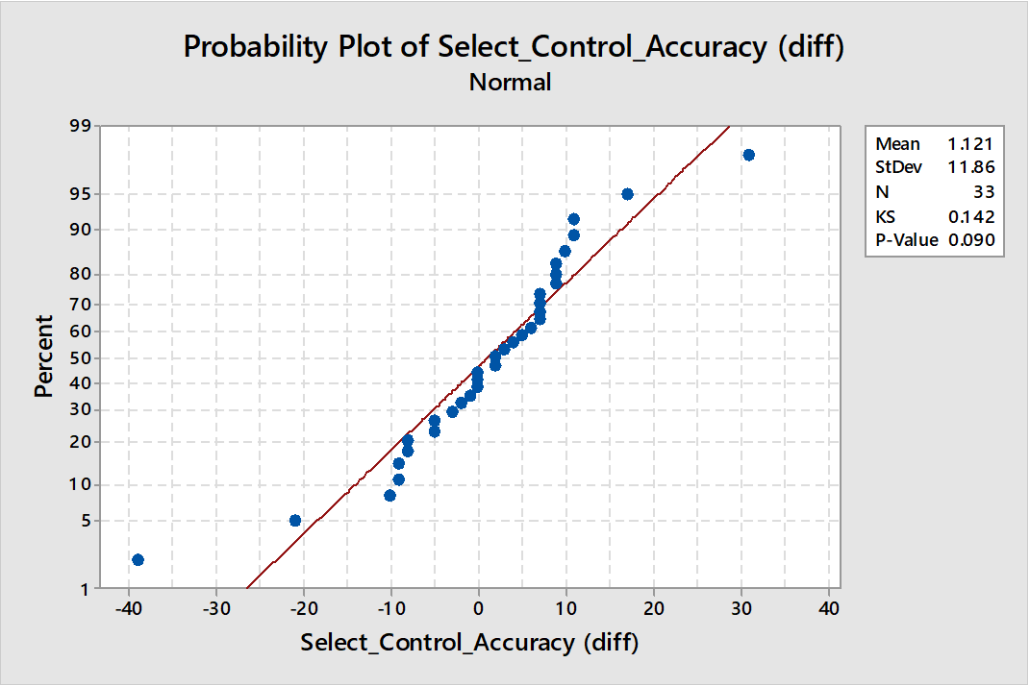
A8. Figure 19: Selective attention - automatic detection speed probability plot - commuting



A8. Figure 20: Selective attention - automatic detection accuracy probability plot - commuting



A8. Figure 21: Selective attention - controlled search speed probability plot - commuting



A8. Figure 22: Selective attention - controlled search accuracy probability plot - commuting

Outputs for $PM_{2.5}$ from candle burning

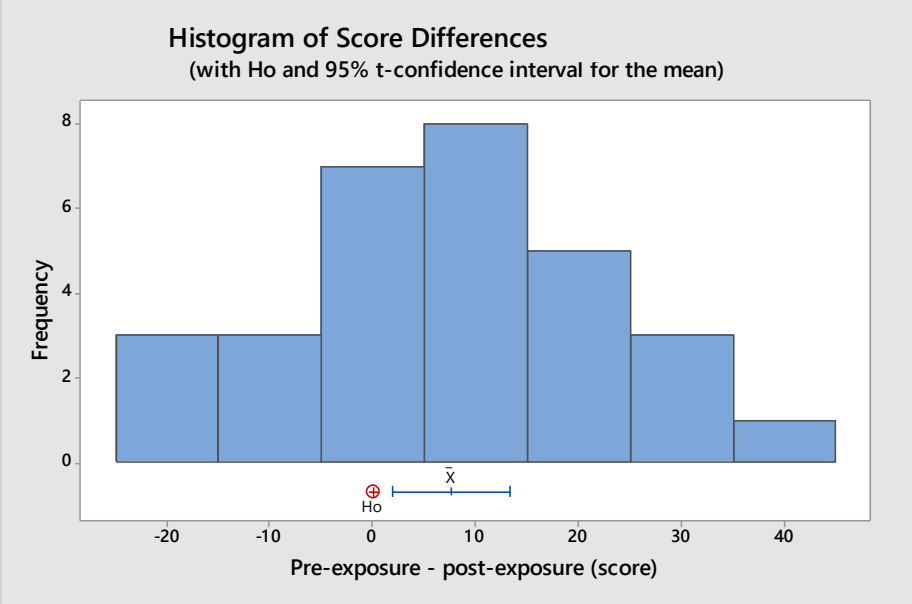
Paired T-Test and CI: No exposureT-Score, exposure_T-Score

Paired T for No exposureT-Score - exposure_T-Score

	N	Mean	StDev	SE Mean
No exposureT-Score	30	47.87	15.88	2.90
exposure_T-Score	30	40.27	16.71	3.05
Difference	30	7.60	15.23	2.78

95% CI for mean difference: (1.91, 13.29)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 2.73 P-Value = 0.011

A8. Figure 23: MMSE analysis for $PM_{2.5}$ from candle burning



A8. Figure 24: Histogram of score differences – MMSE analysis for $PM_{2.5}$ from candle burning

Regression Analysis: t-score difference versus PM2.5 difference

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	63.38	63.38	0.27	0.610
PM2.5 difference	1	63.38	63.38	0.27	0.610
Error	28	6663.82	237.99		
Total	29	6727.20			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
15.4270	0.94%	0.00%	0.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	6.32	3.75	1.69	0.103	
PM2.5 difference	0.0320	0.0621	0.52	0.610	1.00

Regression Equation

t-score difference = 6.32 + 0.0320 PM2.5 difference

Fits and Diagnostics for Unusual Observations

Obs	t-score difference	Fit	Resid	Std Resid	
3	0.00	11.19	-11.19	-0.83	X
5	38.00	7.26	30.74	2.03	R
7	16.00	13.42	2.58	0.25	X

R Large residual
X Unusual X

A8. Figure 25: MMSE t-score difference and $PM_{2.5}$ difference regression analysis

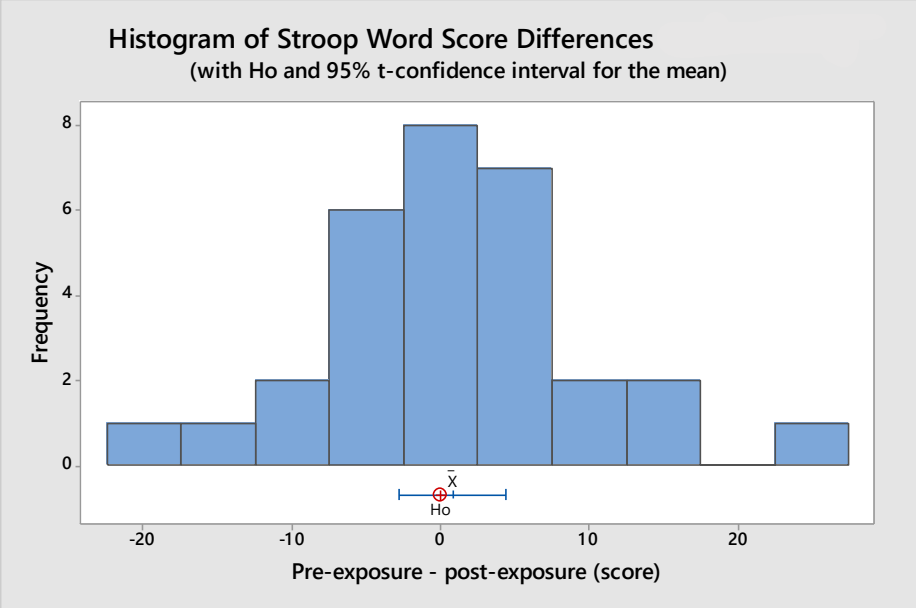
Paired T-Test and CI: Pre-exposureT-Score, Post exposure_T-Score

Paired T for Pre-exposureT-Score - Post exposure_T-Score

	N	Mean	StDev	SE Mean
Pre-exposureT-Score	30	49.10	12.30	2.25
Post exposure_T-Score	30	48.30	14.00	2.56
Difference	30	0.80	9.63	1.76

95% CI for mean difference: (-2.80, 4.40)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.46 P-Value = 0.652

A8. Figure 26: Word analysis for exposure to $PM_{2.5}$ from candle burning



A8. Figure 27: Histogram of score differences – Word analysis for exposure to $PM_{2.5}$ from candle burning

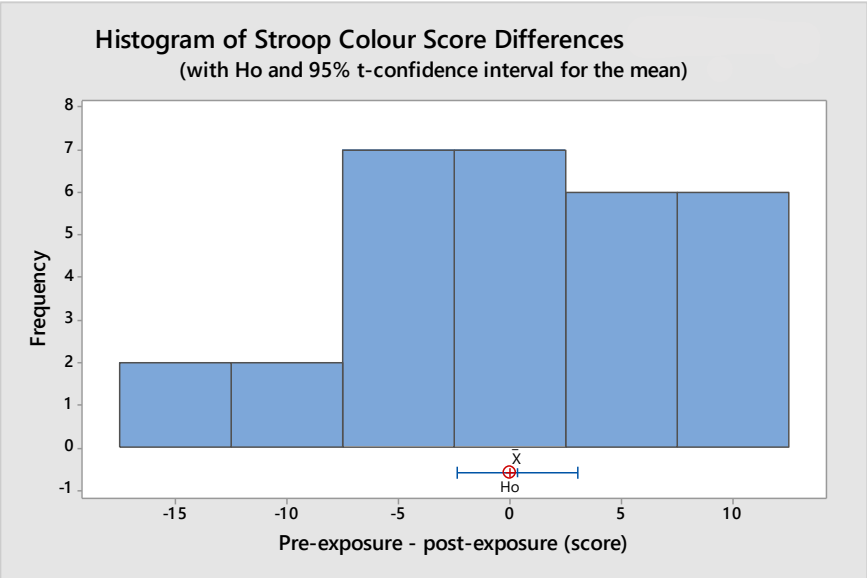
Paired T-Test and CI: Pre-exposureT-Score, Post exposure_T-Score

Paired T for Pre-exposureT-Score - Post exposure_T-Score

	N	Mean	StDev	SE Mean
Pre-exposureT-Score	30	50.37	8.61	1.57
Post exposure_T-Score	30	50.03	9.77	1.78
Difference	30	0.33	7.15	1.31

95% CI for mean difference: (-2.34, 3.00)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.26 P-Value = 0.800

A8. Figure 28: Colour analysis for exposure to $PM_{2.5}$ from candle burning



A8. Figure 29: Histogram of differences- Colour analysis for exposure to $PM_{2.5}$ from candle burning

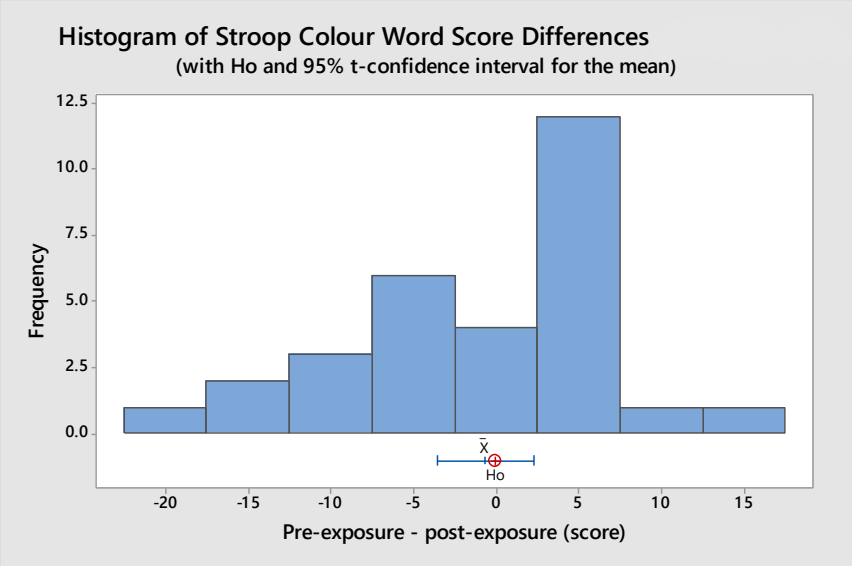
Paired T-Test and CI: Pre-exposureT-Score, Post exposure_T-Score

Paired T for Pre-exposureT-Score - Post exposure_T-Score

	N	Mean	StDev	SE Mean
Pre-exposureT-Score	30	58.70	8.85	1.62
Post exposure_T-Score	30	59.33	9.39	1.71
Difference	30	-0.63	7.77	1.42

95% CI for mean difference: (-3.53, 2.27)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = -0.45 P-Value = 0.658

A8. Figure 30: Colour-Word analysis for exposure to $PM_{2.5}$ from candle burning



A8. Figure 31: Histogram of differences Colour-Word analysis for exposure to $PM_{2.5}$ from candle burning

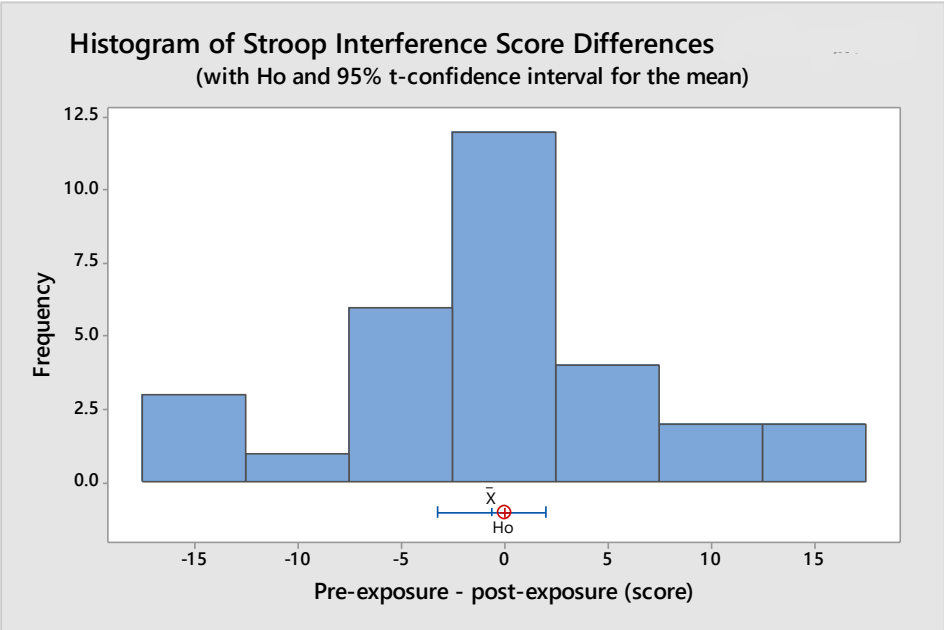
Paired T-Test and CI: Pre-exposureT-Score, Post exposure_T-Score

```
Paired T for Pre-exposureT-Score - Post exposure_T-Score

                          N   Mean  StDev  SE Mean
Pre-exposureT-Score      30  60.67   8.37     1.53
Post exposure_T-Score    30  61.27   8.01     1.46
Difference               30  -0.60   7.11     1.30


95% CI for mean difference: (-3.25, 2.05)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = -0.46  P-Value = 0.647
```

A8. Figure 32: Interference analysis for exposure to $PM_{2.5}$ from candle burning



A8. Figure 33: Histogram of differences – Interference analysis for exposure to $PM_{2.5}$ from candle burning

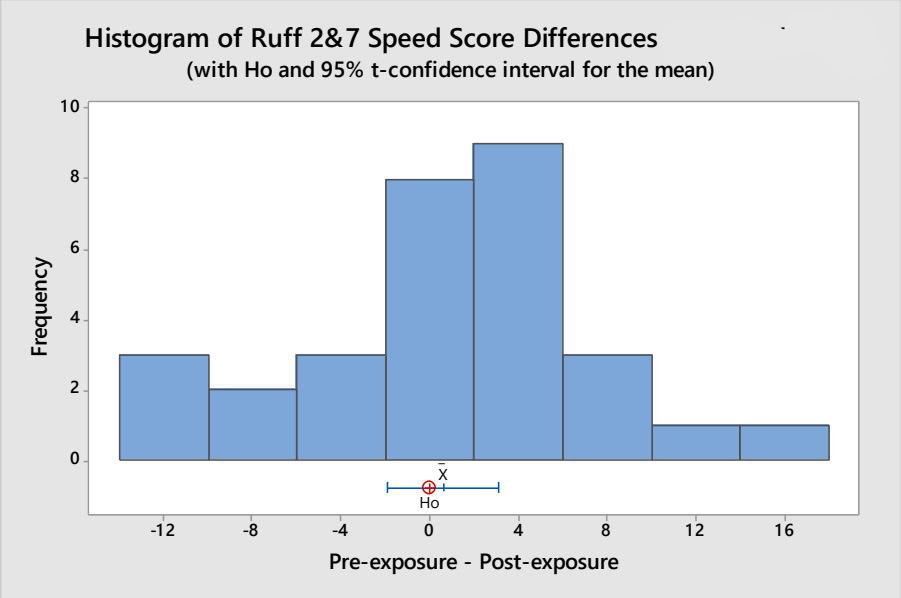
Paired T-Test and CI: Speed T-score (pre), Speed T-score (post)

Paired T for Speed T-score (pre) - Speed T-score (post)

	N	Mean	StDev	SE Mean
Speed T-score (pre)	30	53.50	11.45	2.09
Speed T-score (post)	30	52.90	12.14	2.22
Difference	30	0.60	6.71	1.22

95% CI for mean difference: (-1.91, 3.11)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.49 P-Value = 0.628

A8. Figure 34: Sustained attention, speed analysis for exposure to $PM_{2.5}$ from candle burning



A8. Figure 35: Histogram of score differences – Sustained attention, speed analysis for exposure to $PM_{2.5}$ from candle burning

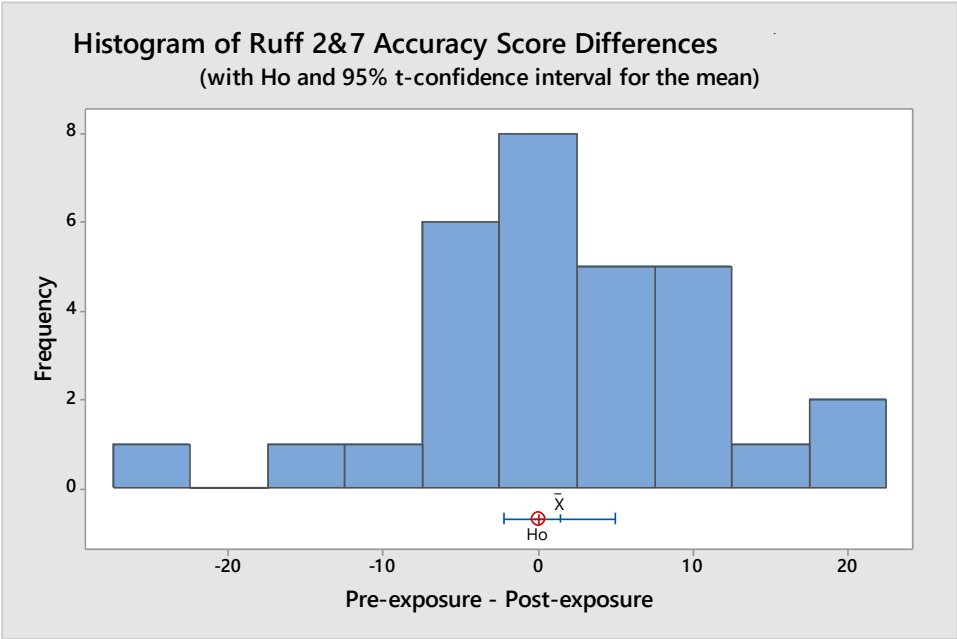
Paired T-Test and CI: Accuracy T-score (pre), Accuracy T-score (post)

```
Paired T for Accuracy T-score (pre) - Accuracy T-score (post)

                          N   Mean  StDev  SE Mean
Accuracy T-score (pre)   30  47.00  10.59     1.93
Accuracy T-score (post)  30  45.63  11.10     2.03
Difference               30   1.37   9.56     1.75


95% CI for mean difference: (-2.20, 4.94)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.78  P-Value = 0.440
```

A8. Figure 36: Sustained attention, accuracy analysis for $PM_{2.5}$ from candle burning



A8. Figure 37: Histogram of score differences - Sustained attention, accuracy analysis for exposure to $PM_{2.5}$ from candle burning

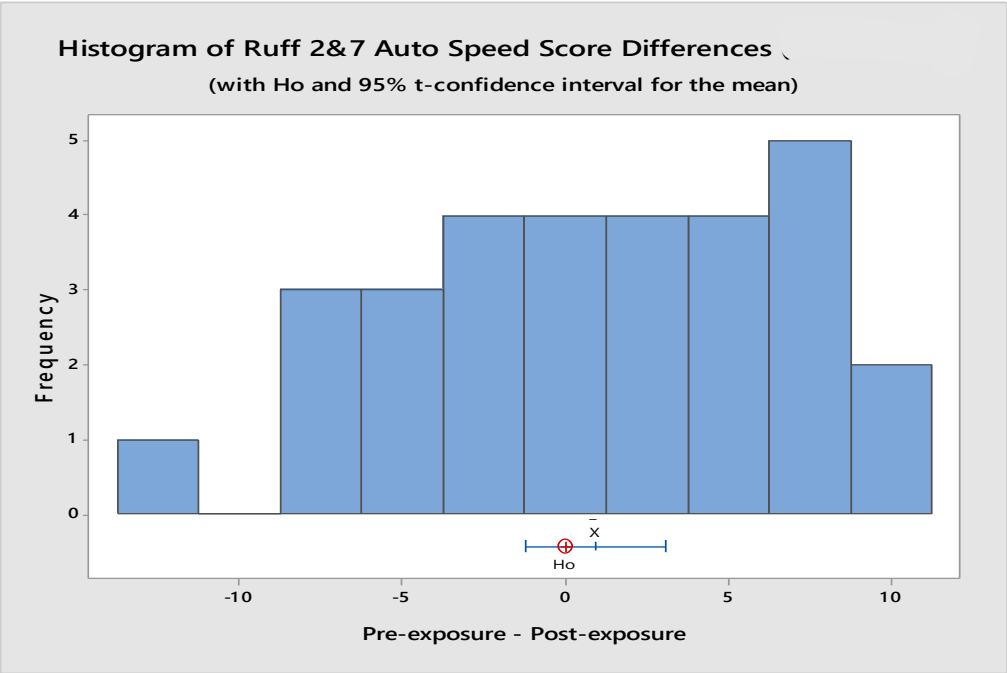
Paired T-Test and CI: Auto Speed (pre), Auto Speed (post)

Paired T for Auto Speed (pre) - Auto Speed (post)

	N	Mean	StDev	SE Mean
Auto Speed (pre)	30	52.47	10.74	1.96
Auto Speed (post)	30	51.53	11.27	2.06
Difference	30	0.93	5.71	1.04

95% CI for mean difference: (-1.20, 3.07)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.90 P-Value = 0.378

A8. Figure 38: Selective attention, automatic detection speed analysis for $PM_{2.5}$ from candle burning



A8. Figure 39: Histogram of score differences - Selective attention, automatic detection speed analysis for exposure to $PM_{2.5}$ from candle burning

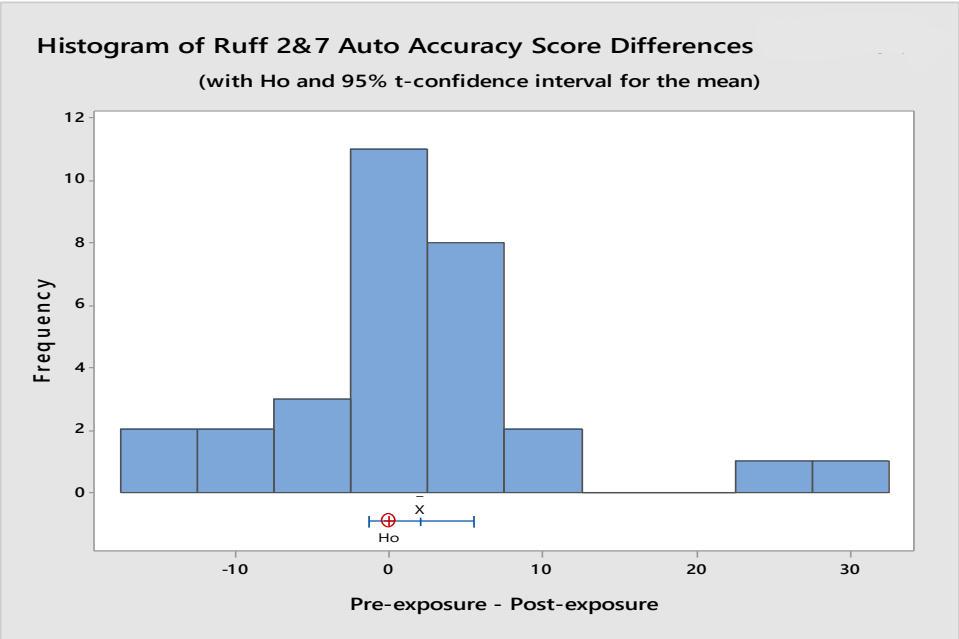
Paired T-Test and CI: Auto Acc (pre), Auto Acc (post)

Paired T for Auto Acc (pre) - Auto Acc (post)

	N	Mean	StDev	SE Mean
Auto Acc (pre)	30	47.77	10.07	1.84
Auto Acc (post)	30	45.70	10.35	1.89
Difference	30	2.07	9.20	1.68

95% CI for mean difference: (-1.37, 5.50)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 1.23 P-Value = 0.228

A8. Figure 40: Selective attention, automatic detection accuracy analysis for exposure to $PM_{2.5}$ from candle burning



A8. Figure 41: Histogram of score differences - Selective attention, automatic detection accuracy analysis for exposure to $PM_{2.5}$ from candle burning

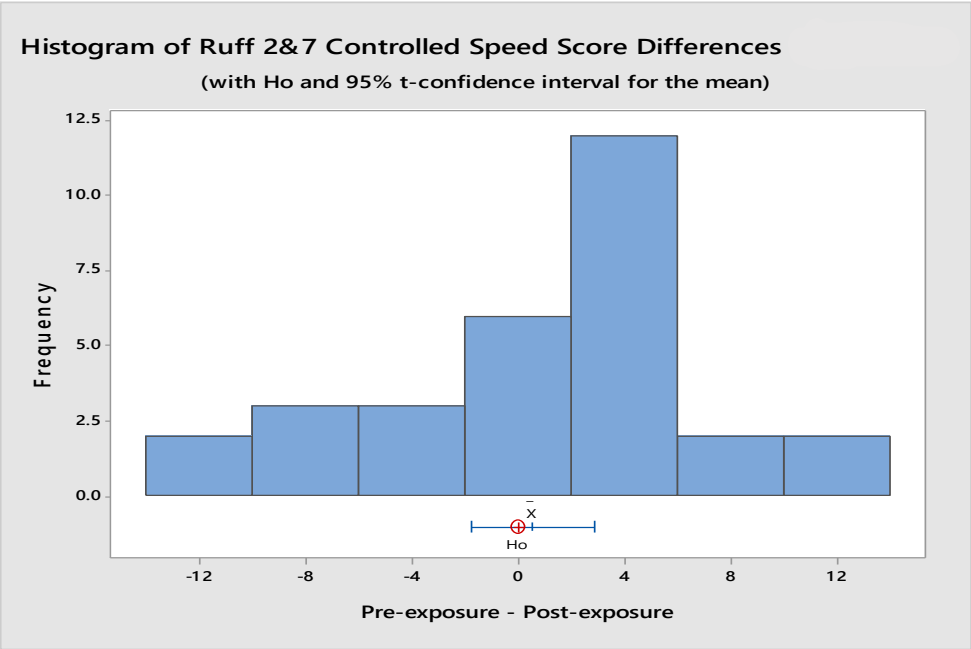
Paired T-Test and CI: Control Speed (pre), Control Speed (post)

Paired T for Control Speed (pre) - Control Speed (post)

	N	Mean	StDev	SE Mean
Control Speed (pre)	30	51.17	12.01	2.19
Control Speed (post)	30	50.60	12.34	2.25
Difference	30	0.57	6.24	1.14

95% CI for mean difference: (-1.76, 2.90)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.50 P-Value = 0.623

A8. Figure 42: Selective attention, controlled search speed analysis for exposure to $PM_{2.5}$ from candle burning



A8. Figure 43: Histogram of score differences - Selective attention, controlled search speed analysis for exposure to $PM_{2.5}$ from candle burning

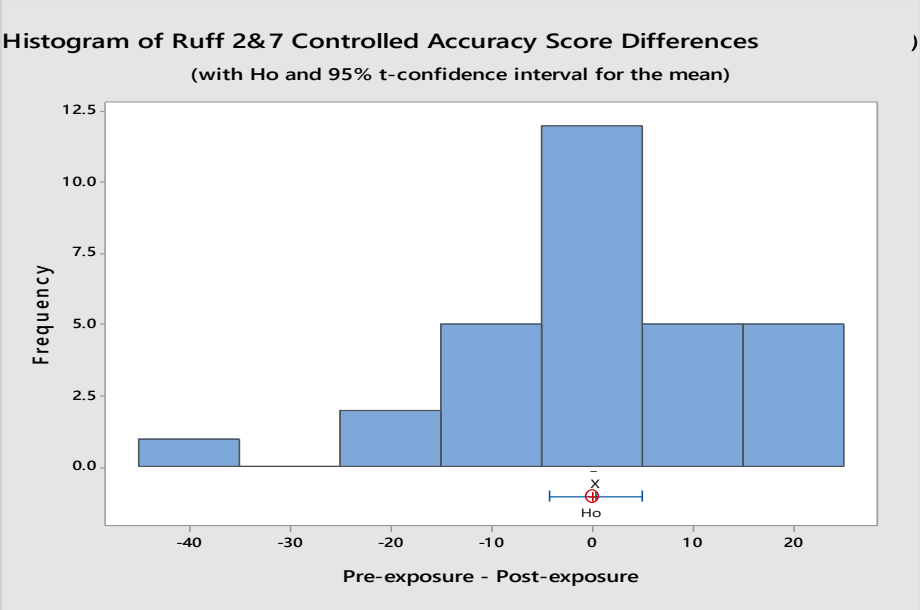
Paired T-Test and CI: Control Acc (pre), Control Acc (post)

Paired T for Control Acc (pre) - Control Acc (post)

	N	Mean	StDev	SE Mean
Control Acc (pre)	30	46.70	12.19	2.23
Control Acc (post)	30	46.30	13.22	2.41
Difference	30	0.40	12.49	2.28

95% CI for mean difference: (-4.26, 5.06)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.18 P-Value = 0.862

A8. Figure 44: Selective attention, controlled search accuracy analysis for exposure to $PM_{2.5}$ from candle burning



A8. Figure 45: Histogram of score differences - Selective attention, controlled search accuracy analysis for exposure to $PM_{2.5}$ from candle burning

Outputs for exposure from commuting

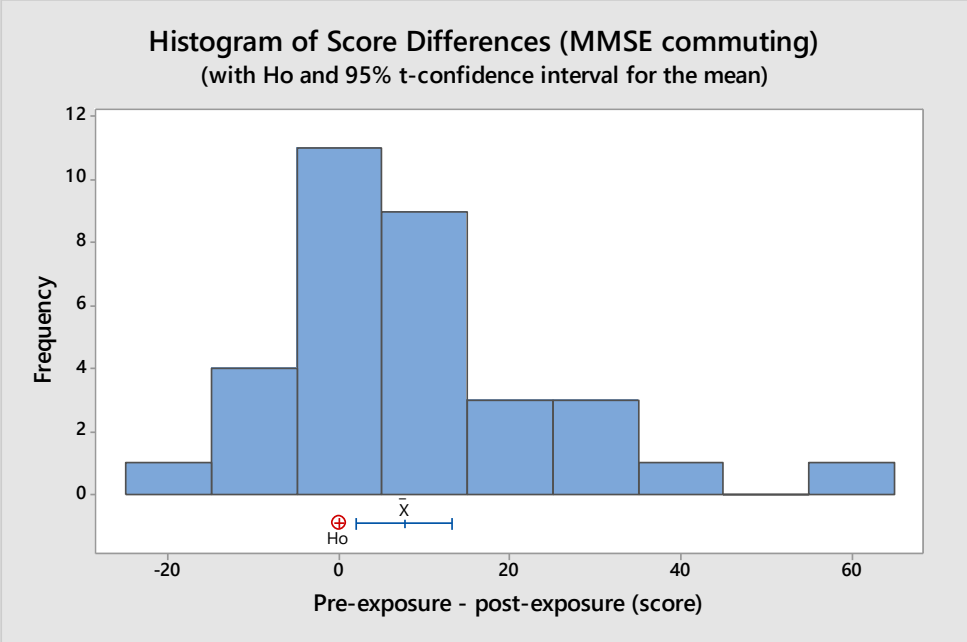
Paired T-Test and CI: Pre-exposureT-Score, Post exposure_T-Score

```
Paired T for Pre-exposureT-Score - Post exposure_T-Score

                          N   Mean  StDev  SE Mean
Pre-exposureT-Score      33  49.55   9.46     1.65
Post exposure_T-Score    33  41.94  15.88     2.76
Difference               33   7.61  15.57     2.71


95% CI for mean difference: (2.08, 13.13)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 2.81  P-Value = 0.008
```

A8. Figure 46: MMSE analysis for exposure to commuting



A8. Figure 47: Histogram of score differences - MMSE analysis for exposure to commuting

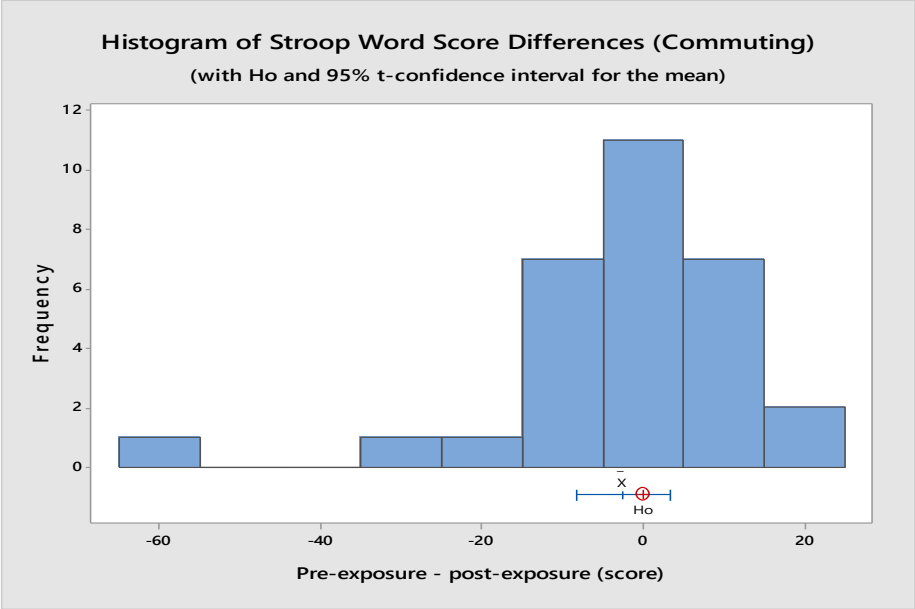
Paired T-Test and CI: Pre-exposureT-Score, Post exposure_T-Score

Paired T for Pre-exposureT-Score - Post exposure_T-Score

	N	Mean	StDev	SE Mean
Pre-exposureT-Score	30	44.60	12.42	2.27
Post exposure_T-Score	30	47.10	12.20	2.23
Difference	30	-2.50	15.72	2.87

95% CI for mean difference: (-8.37, 3.37)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = -0.87 P-Value = 0.391

A8. Figure 48: Word analysis for exposure to pollutants from commuting



A8. Figure 49: Histogram of differences - Word analysis for exposure to pollutants from commuting

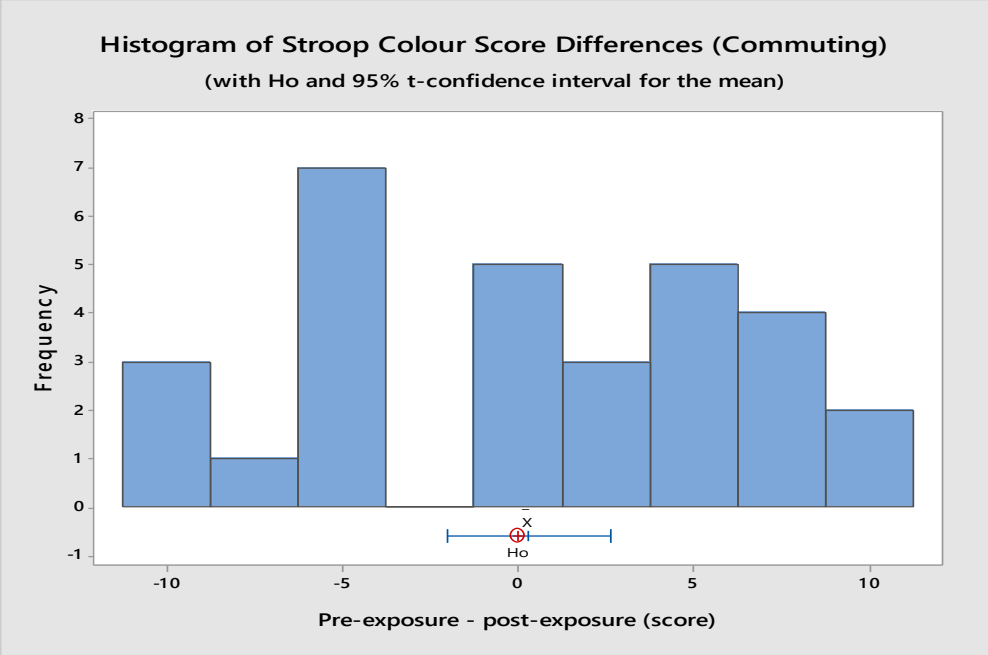
Paired T-Test and CI: Pre-exposureT-Score, Post exposure_T-Score

Paired T for Pre-exposureT-Score - Post exposure_T-Score

	N	Mean	StDev	SE Mean
Pre-exposureT-Score	30	47.07	12.28	2.24
Post exposure_T-Score	30	46.77	10.84	1.98
Difference	30	0.30	6.23	1.14

95% CI for mean difference: (-2.03, 2.63)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.26 P-Value = 0.794

A8. Figure 50: Colour analysis for exposure to pollutants from commuting



A8. Figure 51: Histogram of differences - Colour analysis for exposure to pollutants from commuting

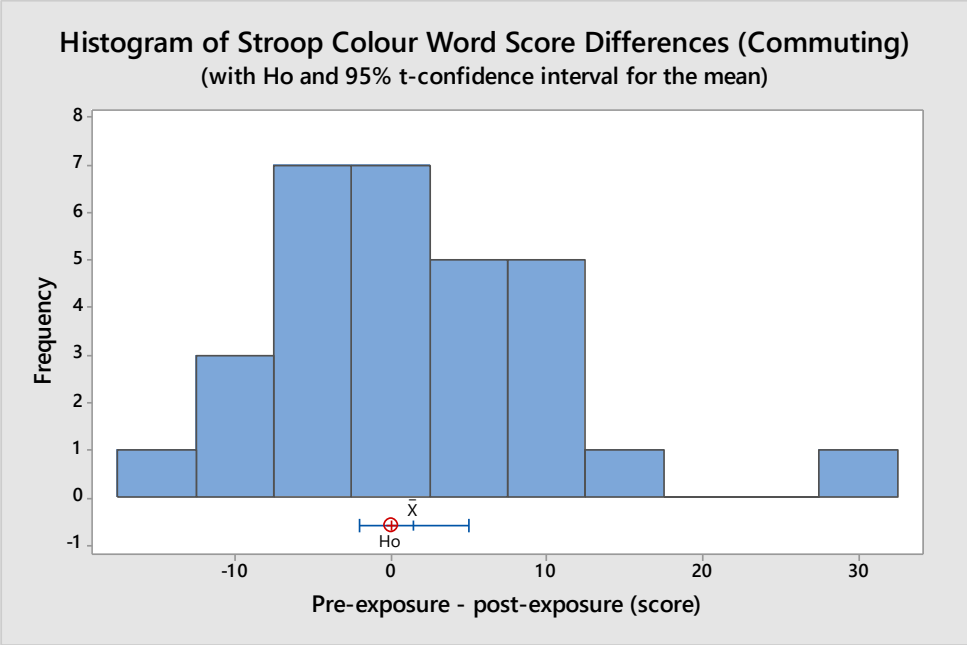
Paired T-Test and CI: No-exposureT-Score, Post exposure_T-Score

```
Paired T for No-exposureT-Score - Post exposure_T-Score

                          N   Mean  StDev  SE Mean
No-exposureT-Score       30  55.90  14.35     2.62
Post exposure_T-Score    30  54.40  11.09     2.02
Difference               30   1.50   9.29     1.70


95% CI for mean difference: (-1.97, 4.97)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.88  P-Value = 0.384
```

A8. Figure 52: Colour-Word analysis for exposure to pollutants from commuting



A8. Figure 53: Histogram of differences - Colour-Word analysis for exposure to pollutants from commuting

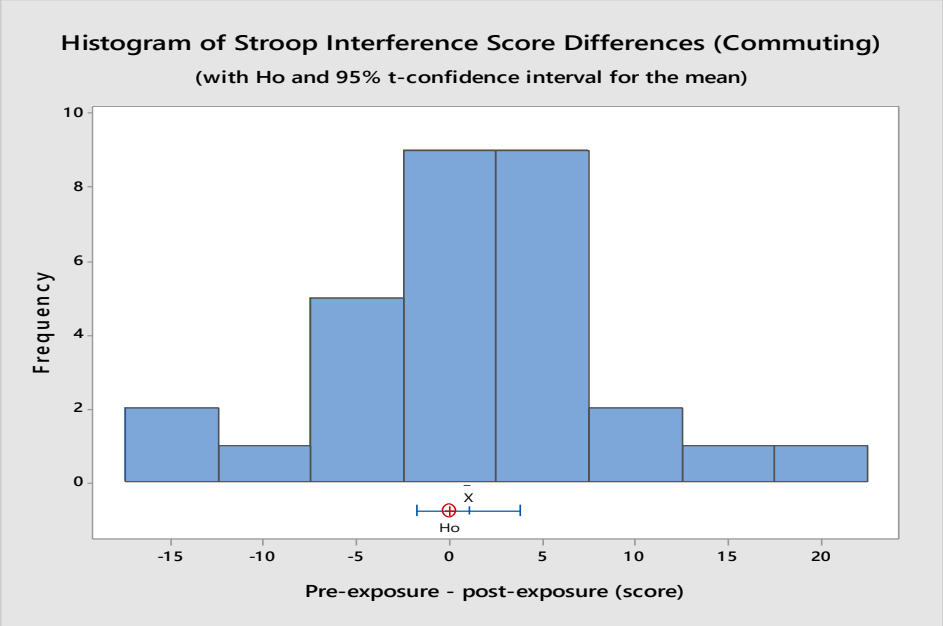
Paired T-Test and CI: Pre-exposureT-Score, Post exposure_T-Score

```
Paired T for Pre-exposureT-Score - Post exposure_T-Score

                         N   Mean  StDev  SE Mean
Pre-exposureT-Score     30  60.10   9.03     1.65
Post exposure_T-Score   30  59.10   7.34     1.34
Difference              30   1.00   7.54     1.38


95% CI for mean difference: (-1.81, 3.81)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.73  P-Value = 0.473
```

A8. Figure 54: Interference analysis for exposure to pollutants from commuting



A8. Figure 55: Histogram of differences - Interference analysis for exposure to pollutants from commuting

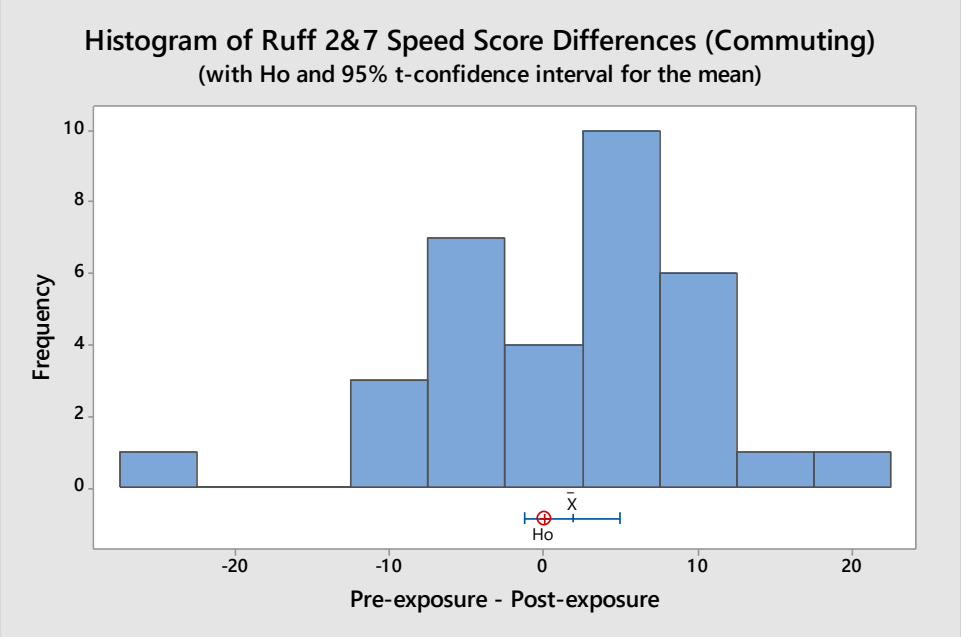
Paired T-Test and CI: Speed T-score (pre), Speed T-score (post)

```
Paired T for Speed T-score (pre) - Speed T-score (post)

                        N   Mean  StDev  SE Mean
Speed T-score (pre)    33  55.27  13.51     2.35
Speed T-score (post)   33  53.42  13.35     2.32
Difference             33   1.85   8.71     1.52


95% CI for mean difference: (-1.24, 4.94)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 1.22  P-Value = 0.232
```

A8. Figure 56: Sustained attention, speed analysis for exposure to pollutants from commuting



A8. Figure 57: Histogram of score differences - Sustained attention, speed analysis for exposure to pollutants from commuting

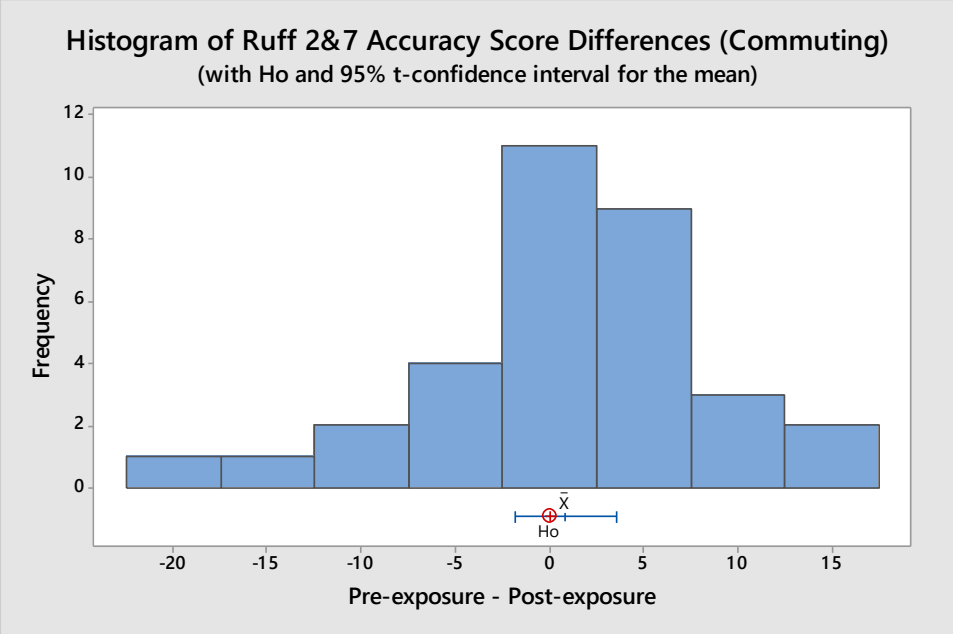
Paired T-Test and CI: Accuracy T-score (pre), Accuracy T-score (post)

```
Paired T for Accuracy T-score (pre) - Accuracy T-score (post)

                           N   Mean  StDev  SE Mean
Accuracy T-score (pre)    33  51.09   6.63     1.15
Accuracy T-score (post)   33  50.24   7.97     1.39
Difference                33   0.85   7.68     1.34


95% CI for mean difference: (-1.87, 3.57)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.63  P-Value = 0.530
```

A8. Figure 58: Sustained attention, accuracy analysis for exposure to pollutants from commuting



A8. Figure 59: Histogram of score differences - Sustained attention, accuracy analysis for exposure to pollutants from commuting

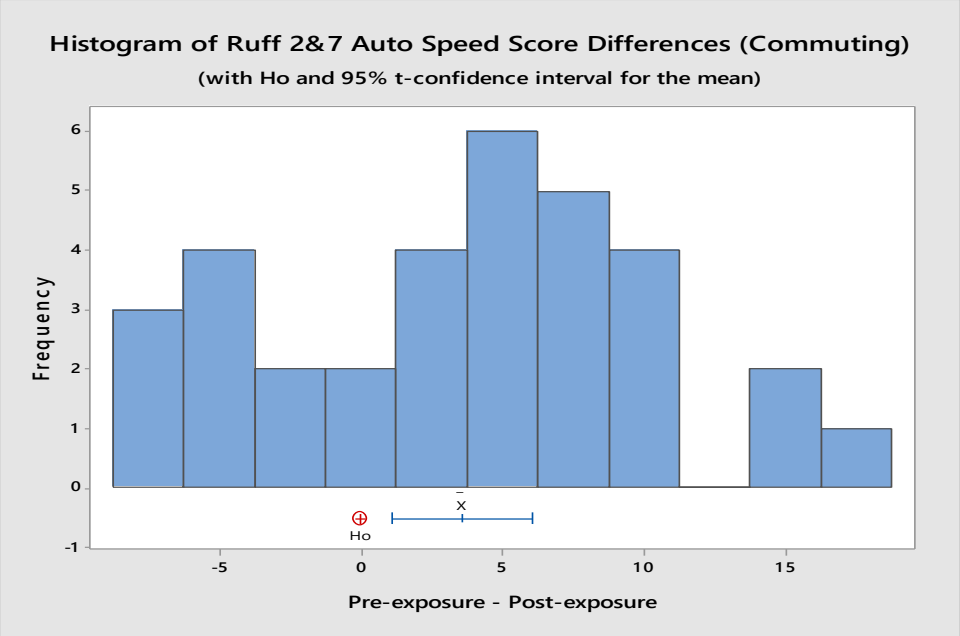
Paired T-Test and CI: Auto Speed (pre), Auto Speed (post)

```
Paired T for Auto Speed (pre) - Auto Speed (post)

                     N   Mean  StDev  SE Mean
Auto Speed (pre)    33  56.18  13.16     2.29
Auto Speed (post)   33  52.61  12.22     2.13
Difference          33   3.58   6.94     1.21


95% CI for mean difference: (1.11, 6.04)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 2.96  P-Value = 0.006
```

A8. Figure 60: Selective attention, automatic detection speed analysis for exposure to pollutants from commuting



A8. Figure 61: Histogram of score differences - Selective attention, automatic detection speed analysis for exposure to pollutants from commuting

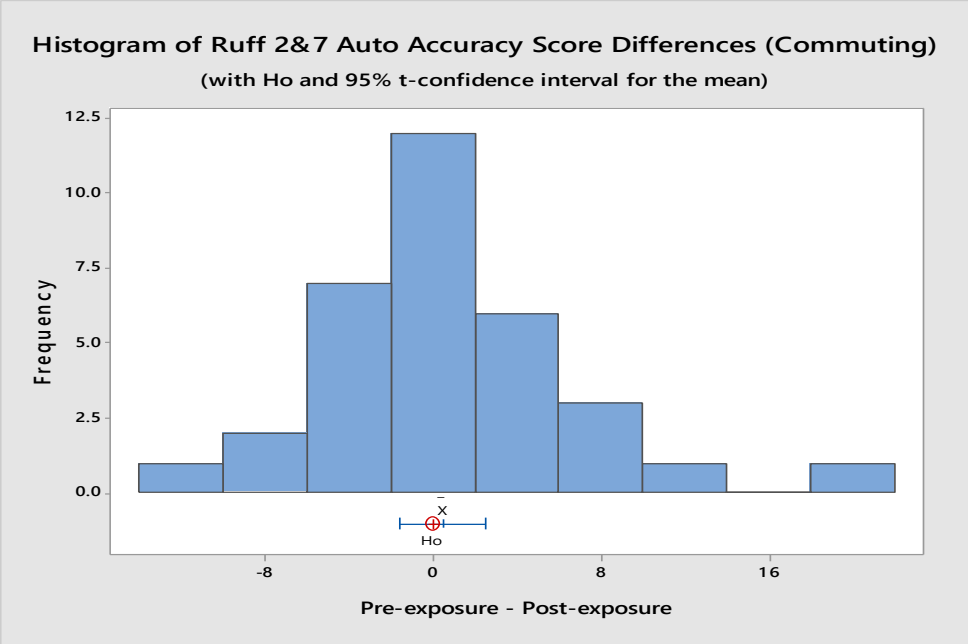
Paired T-Test and CI: Auto Acc (pre), Auto Acc (post)

Paired T for Auto Acc (pre) - Auto Acc (post)

	N	Mean	StDev	SE Mean
Auto Acc (pre)	33	51.85	3.76	0.65
Auto Acc (post)	33	51.36	6.03	1.05
Difference	33	0.48	5.79	1.01

95% CI for mean difference: (-1.57, 2.54)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.48 P-Value = 0.634

A8. Figure 62: Selective attention, automatic detection accuracy analysis for exposure to pollutants from commuting



A8. Figure 63: Histogram of score differences - Selective attention, automatic detection accuracy analysis for exposure to pollutants from commuting

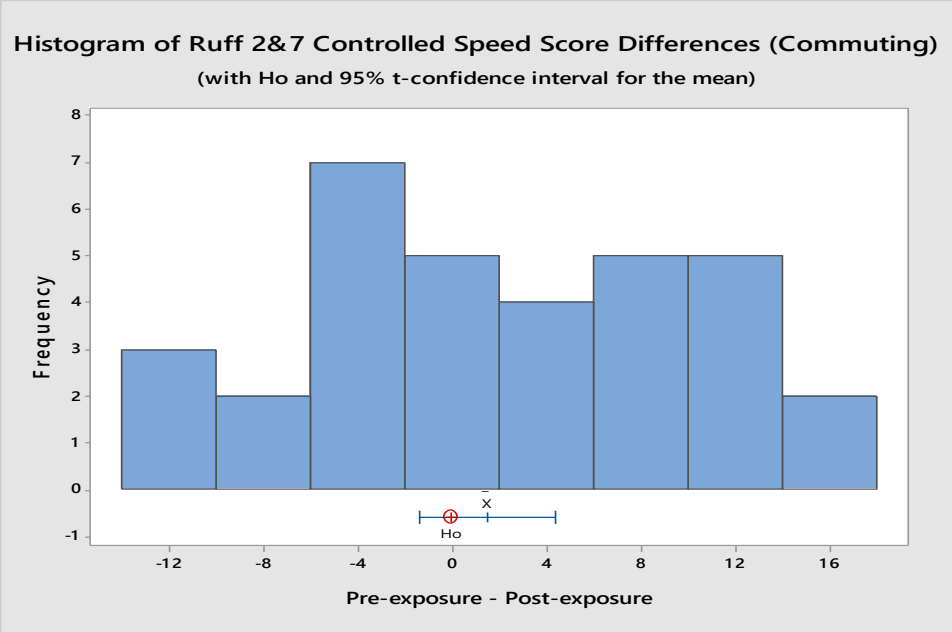
Paired T-Test and CI: Control Speed (pre), Control Speed (post)

Paired T for Control Speed (pre) - Control Speed (post)

	N	Mean	StDev	SE Mean
Control Speed (pre)	33	51.79	15.47	2.69
Control Speed (post)	33	50.30	15.18	2.64
Difference	33	1.48	8.10	1.41

95% CI for mean difference: (-1.39, 4.36)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 1.05 P-Value = 0.300

A8. Figure 64: Selective attention, controlled search speed analysis for exposure to pollutants from commuting



A8. Figure 65: Histogram of score differences - Selective attention, controlled search speed analysis for exposure to pollutants from commuting

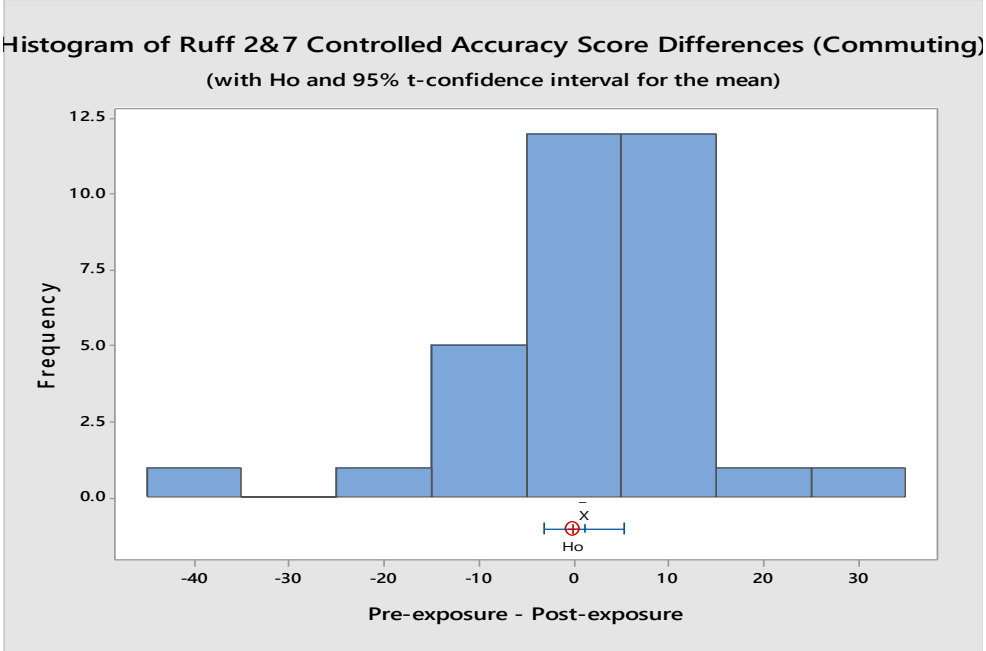
Paired T-Test and CI: Control Acc (pre), Control Acc (post)

Paired T for Control Acc (pre) - Control Acc (post)

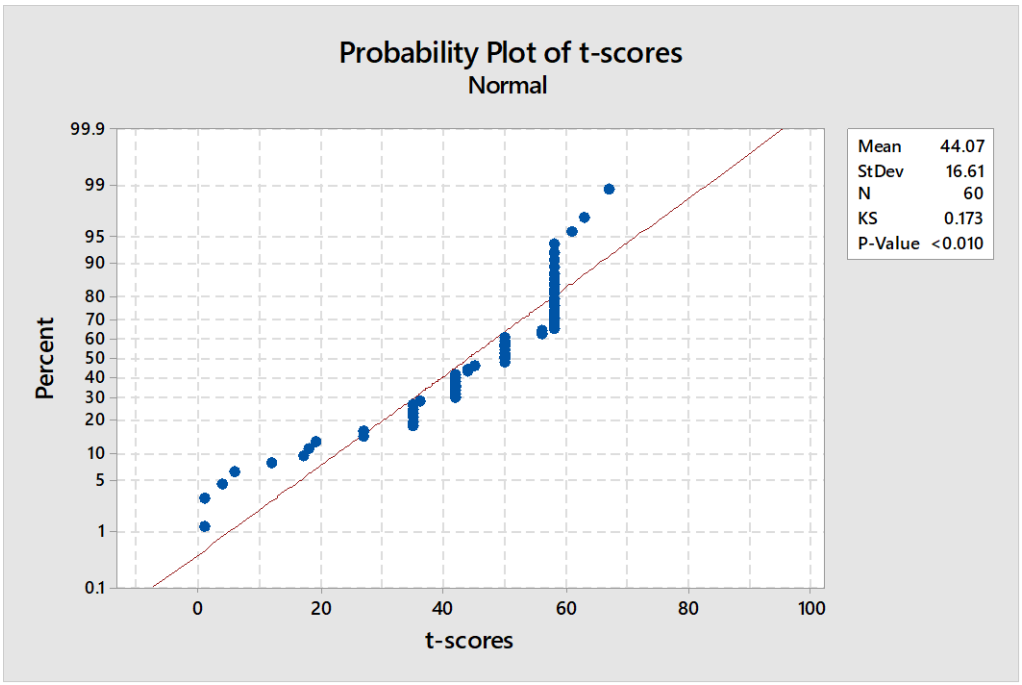
	N	Mean	StDev	SE Mean
Control Acc (pre)	33	50.33	10.59	1.84
Control Acc (post)	33	49.21	11.54	2.01
Difference	33	1.12	11.86	2.06

95% CI for mean difference: (-3.08, 5.33)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 0.54 P-Value = 0.591

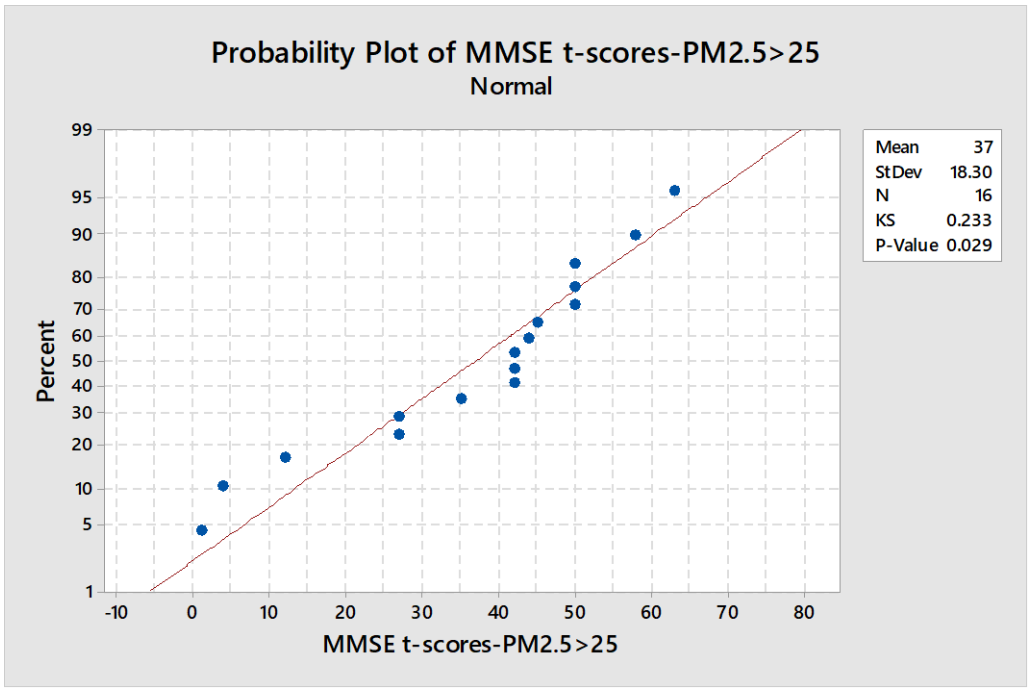
A8. Figure 66: Selective attention, controlled search accuracy analysis for exposure to pollutants from commuting



A8. Figure 67: Histogram of score differences - Selective attention, controlled search accuracy analysis for exposure to pollutants from commuting



A8. Figure 68: Normal probability plot for MMSE t-score differences $PM_{2.5<}25$



A8. Figure 69: Normal probability plot for MMSE t-score differences $PM_{2.5>}25$

Mann-Whitney: MMSE t-scores-PM2.5<25, MMSE t-scores-PM2.5>25

Method

η_1: median of MMSE t-scores-PM2.5<25

η_2: median of MMSE t-scores-PM2.5>25

Difference: $\eta_1 - \eta_2$

Descriptive Statistics

Sample	N	Median
MMSE t-scores-PM2.5<25	44	50
MMSE t-scores-PM2.5>25	16	42

Estimation for Difference

Difference	CI for Difference	Achieved Confidence
8	(-0.0000000, 16)	95.05%

Test

Null hypothesis	$H_0: \eta_1 - \eta_2 = 0$
Alternative hypothesis	$H_1: \eta_1 - \eta_2 \neq 0$

Method	W-Value	P-Value
Not adjusted for ties	1462.50	0.045
Adjusted for ties	1462.50	0.041

A8. Figure 70: Mann-Whitney test for MMSE t-scores after exposure to $PM_{2.5}$ < 25 µg/m³, and after exposure to $PM_{2.5}$ > 25 µg/m³