A PRELIMINARY STUDY ON TRAFFIC-RELATED

OCCUPATIONAL EXPOSURES TO $PM_{2.5}$, CO, AND VOCS IN TRUJILLO, PERU

by

XIANGLU HAN

(Under the Direction of Luke P. Naeher)

ABSTRACT

A traffic-related exposure study was conducted among 58 workers (drivers, vendors, traffic police, and gas station attendants) and 10 office workers as controls in Trujillo, Peru in July 2002. $PM_{2.5}$ was collected using SKC pumps. Carbon monoxide (CO) was measured by Draeger Pac III chemical sensors and Draeger tubes. Volatile organic compounds were sampled using Tenax-packed diffusion tubes and analyzed by a gas chromatograph coupled with mass spectrometer. Newspaper vendors had the highest CO exposure (Mean±SD: 11.4±8.9 ppm) measured by diffusion tubes, office workers being the lowest group (2.0±1.7 ppm). Bus drivers (161±8.9 $\mu g/m^3$) had the highest $PM_{2.5}$ exposure while gas station attendants (64±26.5 $\mu g/m^3$) and office workers (65±8.5 $\mu g/m^3$) were the lowest. Benzene/toluene/ethylbenzene/xylene exposures (BTEX) among gas station attendants (111/254/43/214 $\mu g/m^3$) were much higher than those among combi and taxi drivers. The exposures investigated were of occupational health concern.

INDEX WORDS: Personal exposure, Carbon monoxide, $PM_{2.5}$, VOCs, Traffic-related

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MASTER OF SCIENCE

ATHENS, GEORGIA

2004

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August 2004

ACKNOWLEDGEMENTS

Special thanks go to Manuel Aguilar, Brandon Cassidy, Cameron Carlton, Meagan Kane, Krista Merry, and Kat Smith for their field study information, lab work, data input, or data interpretation assistance. Thanks also to my committee members Dr. Dana Cole and Dr. Marsha Black for guidance in editing this manuscript and to my major professor, Dr. Luke P. Naeher, for his continual support and guidance throughout the two years of my graduate study.

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CHAPTER 1

INTRODUCTION

Chapter 1 provides information contained in each following chapter. Chapter 2 is a literature review on traffic-related air pollutant exposure and epidemiologic studies conducted in the developing world in recent years. This manuscript will be submitted to the journal *Environment International*. It begins with a general introduction of the reasons why traffic-related exposure studies have attracted increasing attention, followed by exposure studies on each of the key traffic-related pollutants (particulate matter, carbon monoxide, ozone, sulfur dioxide, lead, volatile organic compounds, nitrogen dioxide, and polycyclic aromatic hydrocarbons), epidemiologic studies in developing countries, advantages and disadvantages of several monitoring methods, and ends with a brief introduction of ambient air standards and occupational exposure standards established by several agencies. Chapter 3 focuses on a manuscript that will be submitted to *Journal of Occupational and Environmental Hygiene*. This chapter reports results about a preliminary study carried out on occupational exposures to PN2.5, CO, and VOCs among several groups of subjects in Trujillo, Peru in July 2002. It begins with an introduction of the background of the research. After methods and results are presented, implications of the study results and comparisons with findings from other studies are made in the discussion section. It ends with conclusions including future research suggestions.

CHAPTER 2

TRAFFIC-RELATED AIR POLLUTANT EXPOSURE AND EPIDEMIOLOGIC STUDIES IN THE DEVELOPING WORLD [1]

[1] Han, X. and L.P. Naeher. To be submitted to *Environment International*.

Abstract

Exposure assessment and epidemiologic studies in the developing world are important. Recent years have seen an increasing number of traffic-related pollution exposure studies and epidemiologic investigations, however, exposure assessment and epidemiologic data are still not abundant. The differences among measuring methods and a lack of strict quality control in carrying out exposure assessment makes it difficult for the findings to be generalized and the comparisons to be made between studies. In this article, exposure and epidemiologic studies carried out in the developing world on traffic-related exposures to several air pollutants are reviewed. These pollutants include particulate matter (PM), ozone (O_3), carbon monoxide, sulfur dioxide (SO_2), nitrogen dioxide (NO_2), lead (Pb), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs). In addition, it discusses advantages and disadvantages of various monitoring methods (ambient fixed-site monitoring, microenvironment monitoring, and personal exposure assessment using portable samplers) for these pollutants in exposure assessment studies. Also included in this paper is a brief introduction of standards for these pollutants in ambient air or in occupational settings established by the United States Environmental Protection Agency (USEPA), the United States Occupational Safety and Health Administration (OSHA) and World Health Organization (WHO). The review ends with a summary of the limitations and gaps in recent studies and suggestions for future research in the developing world.

Keywords: Air pollution; Developing countries; Traffic-related

Introduction

Air pollution and its public health impacts are drawing increasing concern from the environmental health research community, environmental regulatory agencies, industries, as well as the public. The quality of the air, both indoors and outdoors, is closely related to morbidity and mortality from respiratory and cardiovascular diseases. Common air pollutants that draw intense concerns include particulate matter (PM), ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), lead (Pb), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs).

Association between mortality rate and particulate air pollution has long been studied, but many may have suffered from a lack of control for confounding factors. Dockery DW and coauthors (Dockery et al., 1993) related excess daily mortality from cancer and cardiopulmonary disease to several air pollutants, especially fine particulate matter ($PM_{2.5}$, particulate matter with aerodynamic diameter of equal to or less tan 2.5 microns) in their prospective cohort study. Since then, many other epidemiological studies on the adverse human effects of air pollutants have been carried out, ranging from variations in physiological functions and subclinical symptoms (heart rate variability, peak expiratory flow rate, etc.) to manifest clinical diseases (asthma, chronic obstructive pulmonary disease, stroke, lung cancer, leukemia, etc.), premature births and deaths (Delfino et al., 1998; Naeher et al., 1999; Laden et al., 2000; Suresh et al., 2000; Janssen et al., 2002; Calderón-Garcidueñas et al., 2003; Wilhelm and Ritz, 2003; O'Neill et al., 2004; Preutthipan et al., 2004).

Anthropogenic air pollution sources can be categorized based on different criteria. One criterion is whether the source is mobile or not. The former refers to traffic-related sources, including ground traffic (bus, private car, taxi, combi, motorcycle, etc), underground traffic (metro or subway) and air traffic. And the latter is mainly industrial emissions.

Traffic-related sources of air pollution are drawing increasing concerns from interested exposure assessors, epidemiologists, as well as toxicologists. Ground level traffic vehicles in urban areas are typically gas-fueled or diesel-fueled. And the compositions of gasoline and diesel are not the same in different regions in the world, like lead and benzene content (Romieu, 1997; Verma, and Tombe, 2002), making it complex for the findings in one place to be generalized to other places. This complexity in generalization is further complicated by different meteorological conditions, different percentage of heavy polluters (more motorcycles in the developing world), different maintenance as well as quality of and control measures for vehicles, and exposure profiles of people (Gwilliam, 2003).

Compared with the large volume and varieties of studies carried out in the developed world, exposure assessment and epidemiologic studies in developing countries are relatively scarce. Despite the revised emission standards and technical improvement in pollution control measures, expanding

industrialization and increasing traffic volumes in the developing countries will drastically increase total emissions of many air pollutants, as has been predicted by a study on air pollutant trends in East Asian countries (Klimont et al., 2001).

In this paper, recent investigations in exposure assessment and epidemiologic investigations on several main air pollutants conducted in the developing world are reviewed. Gaps and needs are suggested for future research.

Regulation

In 1997, the US Environmental Protection Agency (EPA) (USEPA, 2001) modified its National Ambient Air Quality Standards (NAAQS) (Table 1), in which the 24-hour and annual average concentration limits for ambient $PM_{2.5}$ were 65 and 15 μg/m^3, respectively. Also included in the standards are CO, PM_{10}, SO_2, NO_2, ozone, and lead. Standards with different time durations are defined because for some pollutants, like ozone and CO, short-term effect is a concern, while for lead and particulate matter, more attention is put on its long-term effect. In addition, which time duration is chosen depends on which durations are more associated with human health effects.

EPA has not proposed any standards for benzene, toluene and other ambient VOCs. But the US Occupational Safety and Health Administration (OSHA) (OSHA,) set 1 ppm (3.19 mg/m^3) and 200 ppm (753.6 mg/m^3) as workplace time-weighted average regulation limits for a normal 8-hour work day or 40-hour work week for benzene and toluene, respectively. The 8-hour and 15-min workplace time-weighted average limits for ethylbenzene set by OSHA were 100 and 125 ppm (434 and 543 mg/m^3), and those for xylene were 100 and 150 ppm (434 and 651 mg/m^3), respectively. These were summarized in Table 2. OSHA set permissible exposure limit for coal tar pitch volatiles at an 8-hour TWA of 0.2 mg/m^3 for occupational workers. However, EPA has not set PAH limits in ambient air.

The World Health Organization (WHO) (WHO, 2001) (Table 3 and Table 4) also has guidelines for these air pollutants, but these are recommendations and not compulsory for governments to follow. $PM_{2.5}$ and PM_{10} guidelines are not available due to the insufficient research information. Because there is no

threshold value for benzene in terms of its carcinogenicity, only unit risk was provided. For PAHs, BaP may serve as an indicator and the risk slope for it was set at 8.7×10^{-2} $[\mu g/m^3]^{-1}$ (Table 4).

It has to be noted that an exposure level lower than the recommended or regulatory standard does not mean that a life-long exposure at such a level is safe. Some standards are 15-min based, others are 1-hour based, still others 8-hour based and yet others 24-hour or annually based. In addition, most of the standards were not established based on NOAELs (No observed adverse effect levels) or LOAELs (lowest observed adverse effect levels). Instead, many factors, including economic feasibility and technical feasibility, have been considered in establishing these standards. So many of the standards, especially those regulatory ones, are much higher than their respective NOAELs or LOAELs. In addition, for many pollutants, due to insufficient pool of evidences, the standards may need to be modified based on new discoveries or new economic and technical feasibilities. For some carcinogens, such as benzene, there seems no NOAEL or LOEAL for its carcinogenicity. The standards for these carcinogens are usually set by considering feasibilities and acceptabilities to the public.

Caution has to be paid even when the exposure level of an air pollutant is lower than LOAEL or NOAEL. For one thing, human exposure to a pollutant has multiple sources other than via air, like water and food. In addition, usually in ambient or occupational environment there are many coexisting air pollutants, several of which may have additive or even synergistic effects. For instance, both benzene and toluene can affect the central nervous system and they usually coexist with each other in the air due to several common resources. Therefore, it will be better if we consider this coexistence when setting standards for these pollutants.

Particulate Matter (PM)

Among common ambient air pollutants, particulate matter is currently under intensive epidemiological and toxicological investigation. Airborne particulate matter refers to particles or droplets of various sizes and chemical compositions present in the air. Previously, environmental epidemiologists had mainly focused on particulate matter with an aerodynamic diameter equal to or less than 10 μg (PM_{10}). As increasing evidence links $PM_{2.5}$ to various respiratory and cardiac effects, more and more

attention is paid to the exposure assessment of $PM_{2.5}$ and its cardiopulmonary impacts (Goldberg et al, 2001; Janssen et al., 2002; Magari et al., 2002).

Anthropogenic airborne particulate matter comes from a variety of sources, which include, but are not restricted to traffic, industries, and domestic heating. Among them, traffic-related particulates have been under intensive scrutiny for at least two reasons. One is due to the evidence that particulates generated from combustion processes, especially diesel exhaust particulates (DEP), are more potent in posing adverse health effects than those from non-combustion process (Laden et al., 2000; Janssen et al., 2002). Another reason is that traffic-generated emissions were estimated to account for more than 50% of the total emissions of particulate matter in the urban areas in highly industrialized countries (Briggs et al., 1997; Wróbel et al., 2000). In London, UK, more than 80% of particulate matter is from road traffic (Department for Transport, 2002). In Athens, Greece, the contribution of road traffic to total $PM_{2.5}$ emission is estimated to be 66.5% (Economopoulou and Economopoulos, 2002). In addition, many cities in the developing world are facing serious problem from traffic-related particulate emissions (Kulkarni and Patil, 1999; Yang, 2002; Shendell and Naeher, 2002; Wang et al., 2003). In Malaysia, air pollutant emissions from traffic vehicles were estimated to account for 82% of the total emissions in 1996 (Afroz et al., 2003). The United Nations estimated that over 600 million people in urban areas worldwide were exposed to dangerous levels of traffic-generated air pollutants (Cacciola et al., 2002).

Airborne particulate pollution is more serious in the developing world than in the developed countries. A particulate characterization study was carried out in five Asian sites: Manila in the Philippines, Hong Kong, Cheju Island in Korea, Sado Ishand, Japan, and Hanoi in Vietnam in 2001. It was found that, except for the site in Japan, annual average $PM_{2.5}$ and PM_{10} concentrations were well above the US EPA annual standard of 15 $\mu g/m^3$ for $PM_{2.5}$ in the four other sites (Cohen et al., 2002). In addition, the chemical composition of the pollutant is also different in different regions under study. For instance, the contents of organic matter (45%) and elemental carbon (28%) in $PM_{2.5}$ were the highest in Manila monitoring site compared to those in the other four sites, which ranged from 7–8.8% for elemental carbon and 8–25% for organic matter. Though the pollutants monitored at the five sites were sampled

using the same method during roughly the same period, their comparison may still suffer from the different locations, since some locations (Cheju Island in Korea and Sado Island in Japan) were more remote than others. Further, this study did not characterize what portion of the concentrations was from traffic emissions. An investigation in Guangzhou, China (Chan et al., 2002) found that $PM_{2.5}$ and PM_{10} levels in several traffic microenvironments were generally much higher than those found in the United States and Europe (Table 5). A five-site survey from February to December 2001 in Nanjing, China (Wang et al., 2003) found that the daytime (8:30 am to 4:30 pm) ambient levels of PM10 and $PM_{2.5}$ were much higher than those found in other studies, with the highest traffic site having an average level of 423 and 632 $\mu g/m^3$ for $PM_{2.5}$ and PM10 respectively. Due to different emission inventory, geographical and meteorological conditions, and socioeconomic background, the physical and chemical characteristics of the ambient particulate matter in urban areas in China and other Asian countries may be different from those in the United States and European countries (Wang et al., 2003; Cohen et al., 2002).

Some traffic-related particulate matter exposure studies and results conducted were summarized in Table 5. Two UK studies and one US study were included in the table for comparisons (Pfeifer et al., 1999; Adams et al., 2001; Riediker et al, 2003). From Table 5, it can be seen that studies on exposure assessment on traffic-related airborne particulate matter, especially $PM_{2.5}$, are scarce the developing world. And particulate levels in the developing countries are clearly higher than those in the developed world.

A study in Mumbai, India (Kulkarni and Patil, 1999) found that 48-hour integrated exposure to respiratory particulate matter (PM_5) among 24 outdoor workers (traffic constables and outdoor workers) during winter months was 322 $\mu g/m^3$. This was 2.25 times that indicated by ambient air quality monitoring data. This showed that ambient air monitoring through a few fixed sites cannot give accurate exposure data of the population, especially those subpopulations that are highly exposed.

A pilot exposure study (Shendell and Naeher, 2002) conducted in three cities in Guatemala in May and June 1997 obtained ground $PM_{2.5}$ and CO levels in busy streets in these urban areas during work hours in the daytime. Levels of $PM_{2.5}$ measured in different zones were drastically different from each other, with the two zones having the highest integrated $PM_{2.5}$ levels of 90 and 100 $\mu g/m^3$ in Guatemala

City and Quetzaltenango, respectively, while the other zones had low levels ranging between 5 and 60 μg/m^3. In an air pollutant exposure study carried out in Bangkok, Thailand (Leong et al., 2001) the 24-hour time-weighted-average (TWA) in ambient air along busy streets was 84.33 μg/m^3.

In May 2002, an exposure study in Mexico City gave exposures of $PM_{2.5}$ for three transport modes during morning and evening rush hours, the arithmetic means (geometric means) of which were 68 (62), 71 (65), 61 (57) μg/m^3 for minibus, bus and metro respectively (Gómez-Perales et al., 2004). In the study, the chemical composition of $PM_{2.5}$ was also investigated, which indicated that only 11% of $PM_{2.5}$ was elemental carbon (EC) compared with higher EC content in $PM_{2.5}$ in other studies. Since EC is considered an indicator of diesel engine emission, these results imply that, compared to gasoline consumption, diesel consumption in Mexico City may be rather low. The large contribution of sulfate (21%) was an indication of high volume of SO_2 that released into the atmosphere in Mexico City, mainly from industries and high sulfur content of the gasoline.

Carbon Monoxide (CO)

In traffic-related exposure studies and epidemiologic investigations, another important pollutant is carbon monoxide (CO), which results from incomplete combustion of diesel or gasoline in traffic engines. High concentrations of CO generally occur in areas with heavy traffic intensity and congestion. Point sources of CO emissions also include industrial processes, non-transportation fuel combustion, and natural sources such as wild forest fires. Indoor sources include leaking gas stoves, heaters, generators, etc. CO is a colorless, odorless and tasteless gas. Unlike NO_2, CO is comparatively stable in the air. After inhalation by the lungs, CO is absorbed by the blood and inhibits oxygen transport by competing with oxygen for combining with hemoglobin and thus leads to hypoxia.

A number of studies have shown that CO pollution is a serious problem in urban areas around the world (Table 6), especially in big cities where traffic intensity is routinely high. Like many other air pollutants, CO levels in urban regions are highly influenced by such factors as traffic density, traffic congestion, and meteorological conditions. Ambient CO concentrations have daily and seasonal variations, as well as complex spatial distributions. Like particulate matter pollution, exposure level of

CO is usually higher in developing countries, as has been frequently demonstrated by various kinds of studies (Table 6). This may have been caused by several factors including poor vehicle maintenance and insufficient use of catalytic converter. Particularly, the study in Mexico City (Gómez-Perales et al., 2004) found lower CO levels in the three transport modes (15, 12, and 7 ppm for minibus, bus, and metro respectively) compared with the previous findings (Fernandez-Bremauntz and Ashmore, 1995) in the same area, though the decrease may be partly due to seasonal difference. A pilot study in urban areas in Guatemala (Shendell and Naeher, 2002) also found low levels of CO (Table 6). Several studies conducted in the European countries and the US were also listed in the the table to assist comparisons (Ashmore et al., 2000; Zagury et al., 2000; Duci et al., 2003; Riediker et al, 2003).

It has to be noted that study outcomes from different regions and countries may not be completely comparable. Due to differences in sampling method, sampling date, time and duration, sampling technique, traffic profile, and meteorological conditions, we can only get a larger picture from these comparisons. And in the several commuting microenvironments studied, private cars and taxi provide highest exposure of CO to commuters compared with other transport modes, mainly public traffic systems (Chan et al., 2002; Duci et al., 2003). An investigation in Bangkok (Leong et al., 2001) revealed that emissions from two-stroke motorcycles were on average 1.5 and 5 times those from other motorcycles in terms of carbon monoxide and hydrocarbon, respectively. In the same study, ambient average level of CO over 8 hours in Bangkok streets was found to be low (6.15 ppm). It has been well established that fixed-site monitoring data of ambient CO level are not accurate and thus not suitable for exposure assessment of commuters. Various models based on street canyon CO concentrations and surrogate factors (traffic factors, street canyon parameters, and meteorological data) are currently being evaluated for their abilities to predict air quality (Venegas and Mazzeo, 2000; Ashmore et al., 2000; Kukkonen et al., 2000; Manning et al., 2000).

Ozone (O_3)

Stratospheric ozone serves a protective role for plants, animals, and human beings by absorbing harmful ultra-violet rays in sunlight. But elevated concentrations of ground-level ozone is a problem to

crops, forestry, and human health. To humans, this oxidant gas can cause eye irritation, respiratory tract damage, increased lung sensitivity to allergens, and chronic damage to the lung structures. Many studies have linked ozone exposure to excessive mortality, especially in the elderly and those with cardiovascular diseases (O'Neill et al., 2004). In ambient air ozone is a secondary pollutant that can be formed through photochemical reactions of primary pollutants in sunlight. These primary pollutants, also called precursors, include traffic-related NOx, CO, and volatile organic compounds (VOCs). Ozone has clear diurnal variation with the highest level in late afternoon or early evening and minimum concentrations at early morning. Seasonal variations can also be found with higher levels in the summer when sunlight is strong. But one exception was found in an ambient ozone monitoring study carried out in Agra, India in 2000–2002 where higher levels of ozone were found in the winter season (28.5 ppb on average in the winter over the two years compared with 22.1 in the summer and 10.9 in the monsoon season) (Satsangi et al., 2004).

In many cities of developing-countries, ambient ozone levels were higher that those in western cities, which may be due to insufficient control measures and bad traffic conditions. In 1996–1997, air pollution data obtained through several fixed sites in different areas in Mexico City (Sánchez-Carrillo et al, 2003) found high levels of ozone with 1-hour maximum ranging from 102 to 140 ppb (Table 7). In southwest metropolitan area of the same city (Calderon-Garciduenas et al., 2003), elevated ozone exposures of 77–84 ppb in daytime and 19–20 ppb at night were found from January to June compared with 61 ppb in daytime and 12 ppb at night in the other half of the year (Table 7). These levels were linked to spirometric changes among a cohort of children living in this area. Mean percents of predicted forced expiratory volume in one second (FEV_1) were 97.7% and 96% when ambient ozone and PM_{10} levels were higher in the two summer periods and the percent was 101.5% when ambient ozone and PM_{10} levels were low in the winter period. And significant differences were found between the two summer FEV_1 and the winter FEV_1. In a study in Bangkok (Leong et al., 2001), the average ambient ozone level (highest hourly TWA of 6.8 ppb) in the urban areas was well below the national standard. Low monthly average ambient levels of ozone of 1–5 ppb were also recorded in a fixed monitoring station in Buenos

Aires, Argentina, where the emissions of gaseous pollutants were mainly from traffic vehicles (Bogo et al., 1999). But caution must be taken in interpreting these results. Ambient ozone exposures at levels below US EPA standards have been demonstrated to be dangerous to some susceptible subgroups, such as the elderly (Delfino et al., 1998) and children (Burnett et al., 2001) in Canada.

Exposure data in several studies were summarized in Table 7. Most of these data were from ambient measurement efforts. For comparison purpose, results from one multi-year monitoring study in Hong Kong (Wu and Chan, 2001) and two US studies (McConnell et al., 2002; Riediker et al, 2003) were also included in the table. Because different studies may differ in their measuring methods, location selection, and the averaging time of the ozone values, these studies are difficult to compare. Currently, most of the studies on ozone exposure assessment have mainly focused on ambient air levels. But ambient levels of ozone may not be a sufficient surrogate for personal exposure. In a study conducted in Mexico City from April to July 1996, personal exposures were measured using personal active samplers among 39 shoe-cleaners working beside traffic streets during their daytime work shift (O'Neill et al., 2003). It was found that personal exposure level (Mean±SD) was 34.4±22.3 ppb while the ambient level of ozone monitored in a rooftop monitoring station (1.84 km away on average from the locations of the subjects) was 84±24.8 ppb. The lower personal levels of ozone may be partly to the scavenging effect of traffic-generated NO_x. However, mixed-effects model showed that the two types of exposure were significantly correlated. This study was not conclusive, though, since the results may have been affected by other factors such as different sampling methods that were used.

Sulfur Dioxide (SO_2)

SO_2 is a colorless gas with a pungent odor. Due to its high water solubility, elevated level of the gas is an irritant to the human body, especially skin, eyes, and the upper respiratory tract. High concentrations of SO_2 in the ambient air are also damaging to crops, forests, aquatic organisms, and many public facilities by forming sulfurous acid or sulfuric acid. It is mainly emitted from combustion of fossil fuels,

either from household heating and cooking, industries or road traffic, especially fuels with high sulfur content.

Due to strict regulation since 1977, ambient concentrations of sulfur dioxide (SO_2) air pollution have declined by approximately 80% in the United States (Greenstone, 2004). However, SO_2 levels are different in different countries and regions. It also has seasonal variations with higher level in the winter. SO_2 air pollution is a more serious problem in the developing world, which may be due to poor pollution control measures on industries and traffic. An emission inventory study in the city of Izmir, Turkey (Elbir and Muezzinoglu, 2004) demonstrated that the emission contributions of traffic-related sources to the total emissions in metropolitan areas were 84% for NOx, 8% for particulate matter and 14% for SO_2.

Like the other pollutants, ambient monitoring data may not indicate real exposure levels of the public. In the Bangkok study (Leong et al., 2001), the average ambient SO_2 level in the urban areas (3.66 ppb for 1-hour average) was much lower than the Thai National Air Quality Standard (300 $\mu g/m^3$ or 114.5 ppb). In an Indian study, ambient average levels monitored at four fixed sites were 3.58–4.17 ppb in the summer, 4.18–4.76 ppb in the monsoon season, and 6.70–7.21 ppb in the winter (Reddy and Ruj, 2003). In Lanzhou, a city in Northwestern China well known for heavy air pollution due to industrial emissions and insufficient annual precipitation, three-year monitoring data (1999-2001) obtained from several rooftop stations gave high ambient levels of SO_2 exposure, especially in the winter (Ta et al., 2004). The three-year average concentrations in the sites were in the range of 35.9–79.4, 8.4–27.5, 1.5–13.0, and 9.5–36.3 ppb in the winter, spring, summer, and fall respectively. Monitoring data in seven Korean major cities (Lee et al., 2000) showed that the average SO_2 level in ambient air was 23.3 ppb, which was lower than the national standard (30 ppb). But regression analysis showed that, after controlling for temperature, humidity, ozone and total suspended particles (TSP), SO_2 at this level was still associated with an elevated rate of mortality.

In an epidemiological study carried out in São Paulo, Brazil (Gouveia, and Fletcher, 2000), several pollutants were monitored in ambient air through several stationary monitoring stations. The daily average SO_2 concentration over 23 months (November 1992 to September 1994) was 6.99 ppb. This SO_2

concentration decreased to 5.85 ppb over the three-year period from January 1998 to December 2000, as provided by the same agency (São Paulo State Sanitary Agency, CETESB) utilizing stationary monitoring sites (Lin et al., 2004). This may be due to strict control measures on traffic emissions and traffic volume in the city.

Though many exposure and epidemiologic studies have been carried out in different countries in the past decades, few have focused solely on traffic-related sources. However, traffic-related sources of SO_2 need to be examined separately for regulatory purpose. Exposure studies and primary results were briefly listed in Table 8. Ambient SO_2 concentrations from a US epidemiologic study were also listed in the table to assist comparison (Delfino et al., 2003).

Lead

Lead is a ubiquitous toxic chemical that can have cumulative adverse effects on the human body. Elevated levels of blood lead can compete with iron during normal blood cell production and ultimately lead to anemia. It can also damage the kidney, liver, and nervous system. Blood lead levels above 70 μg/dL may lead to serious poisoning and a blood concentration of 10 μg/dL can hamper the normal development of IQ in children. An Indian study (Sharma and Pervez, 2003) carried out on lead exposures of 20 traffic personnel indicated that blood lead levels among these subjects were 56.7–101.2 μg/dL while those among controls were only 7.9–31.2 μg/dL. Jakarta school children had an average blood level of 8.6 μg/dL in a study conducted among 397 children before the phase-out of leaded gasoline in July 2001 in the city (Albalak et al., 2003). Compared with the continuing decrease of children's blood lead levels in the United States (CDC, 2000), these findings in the developing countries are higher. In 1998, 7.6%, 2.7%, and 1.2% of the children in the United States had blood lead levels higher than 10, 15, and μg/dL respectively.

Lead in the ambient air is an important air pollution problem in urban areas around the world. The reason for this is that tetraethyl lead was added to gasoline as an antiknocking agent. Since the discovery that lead is detrimental to human health and especially to the development of children, leaded gasoline has been phased out in many countries. As a result, the ambient lead levels, as well as blood lead levels, are

decreasing in both developed and many underdeveloped countries (Schirnding and Fuggle, 1996; Smichowski et al., 2004). However, the use of leaded gasoline has not been totally prohibited in many countries. In many Latin American and Caribbean countries (Romieu, 1997), leaded gasoline is still not widely used, although many countries in this region have introduced unleaded gasoline. Unleaded gasoline was introduced in Mumbai, India in late 1996. One study on monitoring data collected between 1984–1996 in several stationary sites in suburban Mumbai (Tripathi et al., 2001) found that the geometric means in the two most polluted sites were 6.7 and 41.2 μg/m^3, respectively while those in the other sites ranged between 0.1 and 1.2 μg/m^3. An Indian study monitoring the ambient level of lead along a busy road in 1999 gave 24-hour average levels of lead ranging from 1.5 to 3.3 μg/m^3, which were well above the national standards of lead for residential (1.0 μg/m^3) and industrial (1.5 μg/m^3) areas (Jain et al., 2002). Street sweepers in Bangkok's busiest areas were under excess health risks from lead exposure from traffic, as indicated by their significantly lower corpuscular haemoglobin concentration (MCHC) values (Medians: 32.9% for males and 32.8% for females) and significantly higher blood reticulocyte levels (Medians: 1.6% for males and 1.4% for females) measured among 194 sweepers compared to the values among 139 controls (Medians: 33.1% for males and 33.2% for females of MCHC and 0.7% for both males and females of reticulocytes) in one study (Horsawad et al., 1999). This case-control study, may have underestimated the situation since only apparently healthy road sweepers were selected for investigation, thus neglecting the possible unhealthy subgroups of people who were not recruited in the study or had quit the job for health problems. Based on one-month monitoring data (average sampling time ranged between 21 and 49 days) obtained from seven fixed sites (Zheng et al., 2004) in the winter 2001–2002, an airborne lead characterization study found that the average level of lead in ambient air in urban areas in Shanghai was 0.515 μg/m^3 (ranging from 0.167 to 0.854 μg/m^3). However, source analysis showed that only 20% of the concentration was traffic-related and the remaining came from industrial and other processes. The result was not really surprising, since a phase-out program on leaded gasoline was initiated in Shanghai since 1997. But the concentration of lead had no decreasing trend (0.466 μg/m^3 before the phase-out campaign in 1997) which may be due to the increasing industrial emissions.

One study conducted in Cape Town, South Africa (Schirnding and Fuggle, 1996) revealed that, due to substantial intra-urban variations, traffic lead exposure may still pose a health problem to the public. In the study, levels of air lead monitored on main roads with heavy traffic were significantly higher than those off the roads. The highest annual average level was found to be 2.1 μg/m^3 in a site located on the road with biggest volume of vehicles. Similar to the outcomes in other studies, it also found that winter lead levels in the urban environment were significantly higher than that in summer. Lead levels also showed weekday-weekend variation as well as diurnal variation, largely depending on the traffic flow rate.

An eight-day air trace metal monitoring campaign in Buenos Aires, Argentina (Smichowski et al., 2004) found that the average level of lead at nine sampling sites in July 2001 (winter) was 25.1 ng/m^3, a level much lower that those measured in the same city in previous studies.

Another investigation performed in Istanbul, Turkey (Furman and Laleli, 2000) concluded that, despite low lead content in gasoline, some groups of people, like children and adolescent street vendors, were still exposed to traffic-related lead, as indicated by their high level of lead in the scalp hair (11.82 μg/g), about five times that of the control group. In the study groups, traffic lead seemed to be the main source of lead and other sources should be negligible. A dose-response effect was indicated between lead levels in hair and traffic density. Some study results on lead exposures were summarized in Table 9.

Volatile Organic Compounds (VOCs)

Volatile organic compounds are a class of air pollutants sharing the same characteristic of high volatility in the ambient environment. Currently there are more than 300 different kinds of VOCs that can be detected by chromatography. The concentration of VOCs in the air is determined by such processes as emissions, evaporation, deposition, and photochemical reactions under the sunlight. Among traffic-related VOCs, aromatic compounds, including benzene, toluene, ethylbenzene, and isomers of xylene (BTEX), namely m-, o-, and p-xylene, have public health importance. In urban regions, these aromatic VOCs are mainly released from traffic vehicles. Currently, traffic is a predominant source of ambient VOCs in many urban areas in industrialized countries. Besides the penetration of outdoor VOCs, indoor

VOCs may also come from indoor tobacco smoking, household cleaning or degreasing, air freshening, domestic heating, painting, disinfecting, and varnishing, etc.

Among the BTEX compounds, benzene has been widely recognized as a human carcinogen (IARC, 2002) and the others also possess high toxicity, especially to central nervous system in humans. Therefore, this group of VOCs has received much attention in exposure assessment studies. Control plans have been established to lower their levels in ambient air. Just like particulate matter, personal exposure of VOCs cannot be accurately estimated based on several microenvironmental exposure levels and exposure time durations (Gonzalez-Flesca et al., 2000). Exposure data from stationary monitoring sites cannot give the real exposure profile in urban areas, since the level of traffic VOCs decreases drastically as the distance from the main traffic roads increases, causing high spatial variations in the distribution of VOCs. Indeed, the influence of industrial sources on VOC levels along traffic road seemed negligible (Batterman et al., 2002), indicating that air VOCs were so much limited to the small area around the source that even curbside levels were frequently found to have lower concentration of VOCs than the middle lanes of the main roads. Unsurprisingly, in several studies comparing VOC exposures in various commuting modes, roughly the same conclusion was reached: private cars or taxis were exposed to higher levels of VOCs than buses or trains (Chan et al., 2003; Lau and Chan, 2003). Such factors as traffic density, wind, temperature, and city buildings make the spatial variation even greater (Upmanis et al., 2001). Due to the difficulties in directly measuring these small-scale spatial variations, it is a promising job to investigate whether it is feasible to find some traffic indicators as surrogates for traffic-related VOCs and NO_2 exposures. Some good results have been produced but their potential for generalization needs to be validated in further studies (Carr et al., 2002). In one study, traffic volume and the percentage of traffic jam were able to account for 0.76–0.80 of the variability in concentration changes of benzene, toluene, and ethylbenzene. In addition, ambient VOC levels have clear seasonal variation and are higher in the winter season, as was observed in an exposure study in Greece (Kourtidis et al., 2002; Pankow et al, 2003; Ho et al., 2004).

Traffic-related VOC pollution has frequently been demonstrated to be a more serious problem in the countries than in the United States and Europe, as indicated by the VOC data obtained in Karachi, Pakistan (Barletta et al., 2002), a VOC exposure study in India which gave very high levels of VOCs (Mukherjee et al., 2003), and data on BTEX ambient air levels in three cities in Southern China (Wang et al., 2002).. A study in Mexico City gave different levels of benzene at different monitoring sites, some of which were rather high (Bravo et al., 2002). Ten-year fixed-site monitoring data of VOCs in Mexico City (Arriaga-Colina et al., 2004) showed that total VOC levels in the city may have a decreasing trend due to the effective emission control measures, though it was still higher than many other cities in the world. A personal exposure measurement campaign carried out among service station attendants, street vendors, and office workers discovered that BTEX exposures among service station attendants were the highest (310/680/110/490 $\mu g/m^3$) (Romieu, 1999). One study in Australia (Duffy and Nelson, 1997) also reported very high in-vehicle benzene exposures. A study conducted in the US on traffic-related exposures among highway patrol troopers found low levels of VOC exposures (Riediker et al., 2003).

It has to be pointed out that most of these monitoring data are from fixed-site monitoring, while traffic-related exposure in traffic environment may be higher and pose a more serious threat to commuters and traffic-exposed workers. The comparisons between different studies and between developing and developed countries were summarized in Table 10. As indicated in the table, exposures to VOCs were very high for some occupations (petrol pump attendant and shoe stall salesperson).

Nitrogen Dioxide (NO_2)

Nitrogen dioxide, one of the main traffic-related air pollutants and precursors forming photochemical smog (together with VOCs) and ground-level ozone, is currently under intensive investigations. The gas is reddish brown and highly reactive in ambient air. As one member of nitrogen oxides (NO_x), it undergoes a complex chain of chemical and photochemical reactions with nitric oxide (NO), ozone, and other gases. Anthropogenic NO_x emissions are mainly from high-temperature combustion processes, such as those occurring in motor vehicles and power plants. Indoor sources of NO_x may come from tobacco smoke, home heaters, and cooking stoves. Usually the NO_2 in the atmosphere

comes from two sources, either directly from emission sources (primary pollutant) or from chemical reactions in the atmosphere (secondary pollutant). Short-term exposures to the irritant gas may cause airway responsiveness and lung function injury. Long-term exposures may reduce immunity and lead to respiratory infections.

Sharing the same seasonal pattern with several other air pollutants, NO_2 level is usually higher in the winter than in the summer. Many studies showed that NO_2 concentration decreased drastically with increasing distance downwind from traffic (Gilbert et al., 2003; Singer et al., 2004). In a Canadian study (Gilbert et al., 2003), the authors found that wind and the logarithm of distance from a major highway under study may serve as surrogates for traffic NO_2 exposure, which needed further validation. In this Canadian study, the NO_2 levels ranged from 11.9 to 29.3 ppb. Investigation conducted at schools near Northern California freeways (Singer et al., 2004) found highest NO_2 levels (24–30 ppb) in schools downwind and close to freeways.

In developing countries, exposure studies on NO_2 usually indicate higher exposure levels than in the developed world. In a Korean study carried out in 32 shoe stalls beside busy streets in Seoul (Bae et al., 2004), NO_2 levels in shoe stalls and outside were found to be nearly equivalent (57.4 and 58.1 ppb respectively). In this study, outdoor traffic-generated NO_2 may be the main source of indoor exposures. In another Korean study carried out in two cities (Son et al., 2004), 31 taxi drivers were monitored for their in-vehicle personal exposures to NO_2. At the same time the ambient level and their indoor residential level of NO_2 were also measured. It was found that personal exposure (30.3 ppb on average) among these drivers was about 1.6 times the indoor or ambient level. The high exposure mainly came from traffic emissions. One-year monitoring data from several intersections in Calcutta, India (Mondal et al., 2000) showed that NOx levels were highest in the winter (222 $\mu g/m^3$) and lowest in the summer monsoon season (55 $\mu g/m^3$). In October 1998, an exposure study in Buenos Aires, Argentina (Fagundez et al., 2001) didn't find elevated levels of ambient NO_2 at several monitoring sites in urban areas. No site had an average level of NO_2 higher than 40 ppb (Table 11). Low ambient levels of NO_2 (30.16 for 1 hour average) were also found in busy traffic streets in Bangkok, Thailand (Leong et al., 2001) monitored by a few fixed

sites that were close to main roads in the city. Low levels of NO_2 exposures were found among patrol troopers during their work shift while driving the car patrolling highways in the United States (Riediker et al., 2003). These studies were summarized in Table 11.

Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are a group of environmental contaminants that are formed during the incomplete combustion of fossil fuels, or other organic substances like tobacco or food. There are more than 100 different PAHs. PAHs that draw health concerns include acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[a]pyrene (BaP), etc. Several PAHs are human carcinogens, the most famous being benzo[a]pyrene, a highly carcinogenic compound. Some others are mutagenic. A large amount of PAHs are from incomplete combustion in motor vehicle engines, especially heavy-duty and diesel engines (Barakat, 2002). Another main source is tobacco smoke. In the air, they usually coexist as a mixture and most of them are adsorbed on particulate matter, with only a small portion being in a gaseous state, depending on the ambient temperature. PAHs are mainly bounded onto fine respiratory particles (pPAHs), especially ultra-fine particles, though PAH accumulation may occur on larger particle sizes later in the atmosphere (Miguel et al., 2004).

Using a real-time photoelectric aerosol sensor which measured ambient air pPAH levels at an interval of 2 min, a study carried out in Tokyo and Bangkok during the summertime (Chetwittayachan et al., 2002) found that the roadside average concentration of particle-bound PAHs (pPAHs) in Bangkok (52 ng/m^3) was significantly higher than that in Tokyo (29 ng/m^3), but the pPAH level in the general areas in Bangkok (12 ng/m^3) was lower than that of Tokyo (19 ng/m^3). This may be due to the fact that road traffic in Bangkok had more trucks and heavy-duty vehicles, even though Tokyo had a higher percent area of traffic roads and a higher volume of vehicles. In addition, the two sites showed similar diurnal variations as the traffic volume changed. An average of 32 ng/m^3 of total pPAHs in the ambient air was found in a study in heavy traffic areas in Alexandria City, Egypt (Barakat, 2002). It also suggested that, compared with gasoline vehicles, diesel vehicles contributed more to the total emission of urban air PAHs. In the study, the sampling duration was one month, which may have influence on the determined

concentration of PAHs because of the degradation of the samples. In Macao, China, data obtained from four fixed sites (excluding the fifth one which is a non-traffic site) in November 1998 indicated that the total concentrations of 13 PAHs were between the range of 13–51 ng/m^3 at night and 16–80 ng/m^3 day in the daytime (Qi et al., 2002).

An investigation conducted in Zagreb, Croatia (Šišovic et al., 2002) found that the mean summer level (0.05 ng/m^3 for BaP) of PAHs measured by a high volume sampler was much lower than that of the winter (5.12 ng/m^3 for BaP). The possible explanations may be that high summer temperature increased the degradation of PAHs and that winter PAHs also came from sources other than traffic, such as heating. Another explanation for low level of PAHs in summer may be that summer rainfall may clear pPAHs from the ambient air. The annual average of 1.87 ng/m^3 for BaP in this study was lower than annual standards set in many countries.

A PAH personal exposure investigation among 28 traffic policemen and 10 road builders during their working hours (Szaniszló, and Ungváry, 2001) conducted in downtown Budapest, Hungary indicated that PAH exposure levels among these subjects (60.7 and 79.2 ng/m^3 for traffic policemen and road builders respectively) was comparable to those in most of the other European cities. But BaP exposure among traffic policemen (8.16 ng/m^3) was much higher than that among road builders (0.58 ng/m^3). This may be due to the fact that, unlike tar or tar pitch, the asphalt used in road paving is devoid of PAHs. In comparing results obtained from different studies, caution must be paid to seasonal difference and whether the levels measured are personal exposures or ambient levels. Another personal exposure investigation performed among 44 traffic policemen and 45 office policemen in Bangkok, Thailand found that PAH exposures among traffic policemen (72.79 ng/m^3) were much higher than those for office staff (6.88 ng/m^3) (Ruchirawat et al, 2002).

A measurement campaign in Salvador, Brazil found that average BaP level in ambient air near a bus station was 3.06 ng/m^3, while the level in a traffic tunnel was 12.60 ng/m^3 (de P. Pereira, et al., 2002). However, the two levels are not directly comparable, since they were measured in different seasons (Table 12). A very high level in traffic roads came from a study in Mexico City (Marr et al., 2004), where

median level of total particulate-bound PAHs ranged from 60 to 910 ng/m^3. A very high level of in-vehicle exposure (with an average of 929 ng/m^3) to PAHs was found among 5 subjects in Taiwan compared to personal exposure to PAHs from smoke of incense burning (average level of 147 ng/m^3) (Kuo et el., 2003). But the comparison of these findings with other studies is limited by a lack of description of the season during which the study was carried out.

Exposure studies on PAHs and the main findings were summarized in Table 12. Findings from a US study (Levy et al., 2001) and an Italian study (Lodovici et al., 2003) were also included for comparison purpose.

Monitoring Methods

Despite the effort that has been made by epidemiologists from all over the world, health effects studies of particulate matter and gaseous air pollutants have been compromised by the difficulties in the exposure assessment. Traditionally, exposure assessment is focused on ambient air pollution levels, which can be easily obtained by establishing several fixed monitoring sites in the region of interest. Due to spatial variations of the pollutant levels in the study areas, usually exposure monitoring data obtained from these limited number of fixed-sites are not accurate enough for epidemiologic studies. Indeed, many studies have shown that ambient levels of air pollutants were poor predictors of personal exposures (Liard et al., 1999; Kousa et al., 2002; Adgate et al., 2002), a conclusion that was not surprising at all, considering the many microenvironments people occupy in daily life and work. In the Paris study (Liard et al., 1999), on average only 41% of the variance of personal NO_2 exposure among adult subjects could be explained by fixed-site monitoring data, while this percentage is 17% among children. The difference between adults and children may be due to different daily activity patterns. And for ozone, stationary measuring data were also a poor predictor of personal ozone exposure. A US study (Adgate et al., 2002) indicated that only 4% and 26% of personal $PM_{2.5}$ exposure variance were determined by outdoor and indoor levels respectively.

An alternative for this is the adoption of traffic indicators (population density and traffic intensity) and geographic information system (GIS), especially when traffic-related exposure is the main focus. By

collecting traffic indicator information, personal exposure can be estimated. Several studies have used this technique in long-term exposure assessment of particulate matter and other gaseous pollutants (Hoek et al., 2002; Brauer et al., 2003). This method is suitable for long-term exposure assessment for large populations in urban areas. It is an effective method when the main goal is to estimate the exposure profiles of a certain area, and it is better in addressing spatial variations of air pollution levels in a certain area than fixed-site monitoring. But it is not a method to estimate exposure levels for individuals.

The introduction of portable measuring equipment made personal exposure assessment feasible. This increasingly popular method, however, has received much criticism since it is expensive and not suitable for large population study and long-term monitoring. But it has its own advantages. One is that it measures personal exposure directly, which is the very need in rigorous epidemiologic studies. The second strength is that it can be used to address exposure issues for high risk populations. For instance, traffic policemen and drivers are much more exposed to traffic-related air pollutants. It is impossible to measure their exposure using large-scale cost-saving methods, since stationary monitoring is not feasible for these highly mobile groups.

In one investigation (Saarela et al., 2003), researchers had tried to measure VOC exposure levels of subjects in several microenvironments: home indoor, home outdoor and work place outdoor. At the same time, time activity diaries were maintained by each subject. To make comparisons, portable personal samplers were carried by the subjects continuously for 48-hour for measurement of real personal exposure. They found that personal exposure of VOCs was on average 30% higher than the total exposure value calculated with microenvironment exposures and time durations in each of these microenvironments. Other VOCs exposure may come from commuting and other indoor environments, such as sports or recreation places. Therefore, even for people who are typically less mobile than drivers or traffic policemen, portable samplers are also an important tool in assessing their personal exposure levels.

The objective of health risk assessment for many pollutants is not only to protect the health of the general public, but to set limits for these pollutants at levels under which high risk populations and susceptible subpopulations are also acceptably safe. Therefore, personal exposure assessment has its

unique advantages and therefore is irreplaceable in exposure assessment studies. However, compared with fixed-site studies, personal exposure assessment investigations are even more scarce in the developing world. Actually, it has unique advantages to carry out epidemiologic studies utilizing personal exposure data in the developing world. With higher exposure levels in these underdeveloped countries, there is likely to be more chance to quantify the effect of individual pollutants. This necessity is further added by the need for scientific community to complete the dose-response profile through various epidemiologic investigations.

Epidemiological studies on health effects of air pollutants

Many epidemiologic studies have been performed in the United States and Europe to explore the associations between traffic-related air pollutants and a wide spectrum of human health end points including metabolic changes, respiratory changes, birth outcomes, morbidity and mortality from cardiopulmonary diseases or cancers. But there have been only a few epidemiologic investigations in this field in the developing world, which are briefly reviewed in the following paragraphs.

Similar to the epidemiologic studies carried out in the US on the association between ambient fine particulate matter and mortality, a time-series study conducted in Mexico City (Borja-Aburto, et al., 1998) found that, with or without controlling for other air pollutants (ozone and NO2), a 10 $\mu g/m^3$ increase of ambient $PM_{2.5}$ was significantly associated with an elevation of 1.3–1.7% in the total mortality. This study, carried out in a place other than in the US, strengthened the conclusion that ambient air $PM_{2.5}$ pollution is more strongly associated with mortality than ambient coarse particles (Dockery et al., 1993).

In spring 1998, fifty traffic policemen occupationally exposed to CO in Ankara busy intersections were found to have elevated CO concentration in their expired air (Atimtay et al., 2000). These personal exposures ranged from 6 to 24 ppm over about 8 hour's period (3 h to 12 h).

In Hyderabad, India, fourteen healthy traffic policemen were found to have a higher oxidative stress than the control group, as indicated by elevated plasma level of lipid peroxides and decreased levels of various antioxidants in the RBC lysate such as catalase, superoxide dismutase and glutathione peroxidase (Suresh et al., 2000). The resultant loss of balance in the oxidant/antioxidant system may lead to lung

damage and is likely to cause respiratory problems in individuals exposed to elevated traffic-related air pollutants.

An island wide survey in Taiwan (Guo et al., 1999) linked traffic-related air pollutants, especially CO and NOx, to increased prevalence of asthma among middle school children. However, CO and NOx may have just served as indicators for motor vehicle emissions, not really as causative agents, since exposures to several other pollutants, including particulate matter and organic compounds, were not monitored in this study but may have contributed to the elevated prevalence of asthma. Another study in Kaohsiung, Taiwan (Tsai and Huang, 2003) failed to link several air pollutants (PM_{10}, SO_2, NO_2, O_3, and CO) to population mortality using ambient monitoring data, which was contrary to conclusions from many other studies. One explanation may be that air pollution in the city was mainly from industrial exhausts, not traffic emissions. And the six air quality monitoring stations were not designed for obtaining traffic-related air pollution data.

A one-month study was carried out in Bangkok in December 1998, in which 93 asthmatic and 40 nonasthmatic children were randomly selected from a school in close proximity to a highly congested traffic area for a study on the association between particulate matter and prevalence rates. It was found that prevalence rate of asthmatic symptoms was associated with elevated ambient level of PM_{10} (Preutthipan et al., 2004).

Susceptibility to air pollutants is an issue that has been of concern for years. The relative risks among different age groups to exposures of PM_{10}, NO2, SO2, ozone, CO, temperature, and humidity were examined in Seoul, Korea (Ha et al., 2003). It was found that relative risks among neonates were highest compared with those in other groups for the same level of PM_{10} (42.9 $\mu g/m^3$) and SO2 (7.8 ppb) exposures, while the elderly (people over 65 years old) were the most susceptible group to ambient exposure of CO (0.57 ppm), NO_2 (14.9 ppb), and ozone (16.1 ppb).

Conclusions

Exposure assessment and epidemiologic studies in the developing world are important and have advantages. On the one hand, increasing exposure data of traffic-related air pollution will provide

scientific basis for pollution control in local areas. On the other hand, in-depth human health studies in these countries are necessary for assessing the degree of health outcomes of the public and for setting priorities in taking environmental control measures. In addition, epidemiologic investigations in regions with different metrological and socioeconomic backgrounds are helpful in strengthening scientific evidence about the association or causative relationships between these traffic-generated pollutants and various health endpoints.

Recent years has seen an increasing number of traffic-related pollution exposure studies and epidemiologic investigations, many of which are under the cooperation among researchers from developed countries and from developing countries. Though the volume of scientific investigation on traffic-related air pollutants is increasing, exposure assessment and epidemiologic data are still not abundant. The differences among measuring methods and a lack of strict quality control in carrying out exposure assessment make it difficult for the findings to be generalized and the comparisons to be made between studies, which is especially true in exposure assessment research on particulate matter. Many of the existing epidemiologic investigations conducted in these underdeveloped regions suffer from inaccurate exposure assessment and insufficient control for potential confounders.

Therefore, future research in the developing world should emphasize the sharing of technical resources and communications between different countries and the use of standard measuring methods. Source-specific exposure assessment studies and studies using source-specific exposure data need to be more widely carried out since this serves directly as the basis for exposure regulations and public health measures. Source-specific studies are particularly crucial for particulate matter for an additional reason: different sources of particulate matter have different physiochemical compositions and thus different biological potentials (Laden et al., 2000; Janssen et al., 2002).

References

Adams H.S., Nieuwenhuijsen M.J., Colvile R.N., McMullen M.A.S., and Khandelwal P. Fine particle ($PM_{2.5}$) personal exposure levels in transport microenvironments, London, UK. The Science of the Total Environment 2001; 279: 29–44

Adgate J.L., Ramachandrana G., Pratt G.C., Waller L.A., and Sexton K. Spatial and termporal variability in outdoor, indoor, and personal $PM_{2.5}$ exposure. Atmospheric Environment 2002; 36: 3255–65

Afroz R., Hassan M.N., and Ibrahim N.A. Review of air pollution and health impacts in Malaysia. Environmental Research 2003; 92: 71–7

Albalak R., Noonan G., Buchanan S., Flanders W.D., Gotway-Crawford C., Dennis Kim, et al. Blood lead levels and risk factors for lead poisoning among children in Jakarta, Indonesia. The Science of the Total Environment 2003; 301: 75–85

Arriaga-Colina J.L., West J.J., Sosa G., Escalona S.S., Ordúñez R.M., and Cervantes A.D.M. Measurements of VOCs in Mexico City (1992–2001) and evaluation of VOCs and CO in the emissions inventory. Atmospheric Environment 2004; 38: 2523–33

Ashmore M.R., Batty K., Machin F., Gulliver J., Grossinho A., Elliott P., et al. Effects of traffic management and transport mode on the exposure of school children to carbon monoxide. Environmental Monitoring and Assessment 2000; 65: 49–57

Atimtay A.T., Emri S., Bagci T., and Demir A.U.. Urban CO exposure and its health effects on traffic policemen in Ankara. Environmental Research Section A 2000; 82: 222–30

Bae H., Yang W., and Chung M. Indoor and outdoor concentrations of RSP, NO2 and selected volatile organic compounds at 32 shoe stalls located near busy roadways in Seoul, Korea. Science of the Total Environment 2004; 323: 99–105

Barakat A.O. PAHs and petroleum biomarkers in the atmospheric environment of Alexandria City, Egypt. Water, Air, and Soil Pollution 2002; 139: 289–310

Barletta B., Meinardi S., Simpson I.J., Khwaja H.A., Blake D.R., and Rowland F.S. Mixing ratios of volatile organic compounds (VOCs) in the atmosphere of Karachi, Pakistan. Atmospheric Environment 2002; 36: 3429–43

Batterman S.A., Peng C.Y., and Braun J. Levels and composition of volatile organic compounds on commuting routes in Detroit, Michigan. Atmospheric Environment 2002; 36: 6015–30

Bogo H., Negri R.M., and Román E.S. Continuous measurement of gaseous pollutants in Buenos Aires city. Atmospheric Environment 1999; 33: 2587–2598

Bono R., Scursatone E., T. Schilirò, and Gilli G.. Ambient air levels and occupational exposure to benzene, toluene, and xylenes in Northwestern Italy. Journal of Toxicology and Environmental Health, Part A 2003; 66: 519–31

Borja-Aburto V.H., Castillejos M., Gold D.R., Bierzwinski S., and Loomis D. Mortality and Ambient Fine Particles in Southwest Mexico City, 1993–1995. Environmental Health Perspectives 1998; 106: 849–55

Brauer M., G. Hoek, P. van Vliet, K. Meliefste, P. Fischer, U. Gehring, et al. Estimating Long-Term Average Particulate Air Pollution Concentrations: Application of Traffic Indicators and Geographic Information Systems. Epidemiology 2003; 14: 228–39

Bravo H., Sosa R., Sánchez P., Bueno E., and González L. Concentrations of benzene and toluene in the atmosphere of the southwestern area at the Mexico City Metropolitan Zone. Atmospheric Environment 2002; 36: 3843–9

Briggs D.J., Collins S., Elliott P., Ficher P. , Kingham S. , Lebret E., et al. Mapping urban air pollution using GIS: a regression-based approach. Int J Geographical Information Science 1997; 11: 699–718

Burnett R.T., Smith-Doiron M., Stieb D., Raizenne M.E., Brook J.R., Dales R.E., et al. Association between ozone and hospitalization for acute respiratory diseases in children less than 2 years of age. American Journal of Epidemiology 2001; 153: 444–52

Cacciola R.R., Sarva M., and Polosa R. Adverse respiratory effects and allergic susceptibility in relation to particulate air pollution: flirting with disaster. Allergy 2002; 57: 281–6

Calderón-Garcidueñas L., Mora-Tiscareño A., Fordham L.A., Valencia-Salazar G., Chung C.J., Rodriguez-Alcaraz A., et al. Respiratory damage in children exposed to urban pollution. Pediatric Pulmonology 2003; 36: 148–61

Carr D., van Ehrenstein O., Weiland S., Wagner C., Wellie O., Nicholai T., et al. Modeling annual benzene, toluene, NO2, and soot concentrations on the basis of road traffic characteristics. Environmental Research Section A 2002; 90: 111–8

CDC. Blood lead levels in young children --- United states and selected states, 1996–1999. MMWR Morb Mortal Wkly Rep 2000; 49:1133–7

Chan L.Y., Lau W.L., Zou S.C., Cao Z.X., and Lai S.C. Exposure level of carbon monoxide and respirable suspended particulate in public transportation modes while commuting in urban area of Guangzhou, China. Atmospheric Environment 2002; 36: 5831–40

Chan L.Y., Lau W.L., Wang X.M., and Tang J.H. Preliminary measurements of aromatic VOCs in public transportation modes in Guangzhou, China. Environment International 2003; 29: 429–35

Chen B., Hong C., and Kan H. Exposures and health outcomes from outdoor air pollutants in China. Toxicology 2004; 198: 291–300

Chetwittayachan T., Shimazaki D., and Yamamoto K. A comparison of temporal variation of particle-bound polycyclic aromatic hydrocarbons (pPAHs) concentration in different urban environments: Tokyo, Japan, and Bangkok, Thailand. Atmospheric Environment 2002; 36: 2027–37

Cohen D.D., Garton D., Stelcer E., Wang T., Poon S., Kim J., et al. Characterisation of $PM_{2.5}$ and PM10 Fine Particle Pollution in Several Asian Regions. 16th Int. Clean Air Conf. Christchurch, NZ, 18–22 Aug 2002

Delfino R.J., Murphy-Moulton A.M., and Becklake M.R. Emergency room visits for respiratory illnesses among the elderly in Montreal: association with low level ozone exposure. Environmental Research Section A 1998; 76: 67–77

de P. Pereira P.A., de Andrade J.B. and Miguel A.H. Measurements of semivolatile and particulate polycyclic aromatic hydrocarbons in a bus station and an urban tunnel in Salvador, Brazil. J. Environ. Monit. 2002; 4: 558–561

Department for Transport (UK). Sources of Particulate Matter in Urban Areas: TRAMAQ Project UG 250 September 2002

Dockery D.W., Pope C.A., Xu X., Spengler J.D., Ware J.H., Fay M.E., et al. An Association between Air Pollution and Mortality in Six U.S. Cities. The New England Journal of Medicine 1993; 329: 1753–9

Duci A., Chaloulakou A., and Spyrellis N. Exposure to carbon monoxide in the Athens urban area during commuting. The Science of the Total Environment 2003; 309: 47–58

Duffy B.L, and Nelson P.F. Exposure to emissions of 1,3-butadiene and benzene in the cabins of moving motor vehicles and buses in Sidney, Australia. Atmospheric Environment 1997; 31: 3877–85

Economopoulou A.A., and Economopoulos A.P. Air pollution in Athens Basin and health risk assessment. Environmental Monitoring and Assessment 2002; 80: 277–99

Edwards R.D., Jurvelin J., Saarela K., and Jantunen M. VOC concentrations measured in personal samples and residential indoor, outdoor and workplace microenvironments in EXPOLIS-Helsinki, Finland. Atmospheric Environment 2001; 35: 4531–43

Elbir T., and Muezzinoglu A. Estimation of emission strengths of primary air pollutants in the city of Izmir, Turkey. Atmospheric Environment 2004; 38: 1851–7

Fagundez L. A., Fernández V. L., Marino T. H., Martín I., Persano D. A., Rivarola Y benítez M., et al. Preliminary Air Pollution Monitoring in San Miguel, Buenos Aires. Environmental Monitoring and Assessment 2001; 71: 61–70

Fernandez-Bremauntz, A.A., Ashmore, M.R. Exposure of commuters to carbon monoxide in Mexico City—I. Measurement of in-vehicle concentrations. Atmospheric Environment 1995; 29: 525–532.

Furman A., and Laleli M. Semi-occupational exposure to lead: a case study of child and adolescent street vendors in Istanbul. Environmental Research Section A 2000; 83: 41–5

Gilbert N.L., Woodhouse S., Stieb D.M., and Brook J.R. Ambient nitrogen dioxide and distance from a major highway. The Science of the Total Environment 2003; 312: 43–6

Goldberg M.S., Burnett R.T., Bailar J.C., Brook J., Bonvalot Y., Tamblyn R., et al. The Association between Daily Mortality and Ambient Air Particle Pollution in Montreal, Quebec 2. Cause-Specific Mortality. Environmental Research Section A 2001; 86: 26–36

Gómez-Perales J.E., Colvile R.N., Nieuwenhuijsen M.J., Fernández-Bremauntz A., Gutiérrez-Avedoy V.J., Páramo-Figueroa V.H., et al. Commuters' exposure to $PM_{2.5}$, CO, and benzene in public transport in the metropolitan area of Mexico City. Atmospheric Environment 2004; 38: 1219–29

Gonzalez-Flesca N., Bates M.S., Delmas V., and Cocheo V. Benzene exposure assessment at indoor, outdoor, and personal levels. The French contribution to the life MACBETH programme. Environmental Monitoring and Assessment 2000; 65: 59–67

Gouveia N., and Fletcher T. Respiratory diseases in children and outdoor air pollution in São Paulo, Brazil: a time series analysis. Occup Environ Med 2000; 57: 477–483

Greenstone M. Did the Clean Air Act cause the remarkable decline in sulfur dioxide concentrations? Journal of Environmental Economics and Management. 2004; 47: 585–611

Guo Y.L., Lin Y.C., Sung F.C., Huang S.L., Ko, Y.C., Lai J.S., et al. Climate, traffic-related air pollutants, and asthma prevalence in middle school children in Taiwan. Environmental Health Perspectives 1999; 107: 1001–6

Gwilliam K. Urban transport in developing countries. Transport Reviews 2003; 23 (2): 197–216

Ha E.H., Lee J.T., Kim H., Hong Y.C., Lee B.E., Park H.S., et al. Infant Susceptibility of Mortality to Air Pollution in Seoul, South Korea. Pediatrics 2003; 111: 284–290

Ho K.F., Lee S.C., Guo H., and Tsai W.Y. Seasonal and diurnal variations of volatile organic compounds (VOCs) in the atmosphere of Hong Kong. Science of the Total Environment 2004; 322: 155–66

Hoek G., Brunekreef B., Goldbohm S., Fischer P., and van den Brandt P.A. Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. Lancet 2002; 360: 1203–9

Horsawad V., Pongpaew P., Tungtrongchitr R., Phonrat B., Vudhivai N., Chanjanakitskul S., et al. Lead exposure, urinary δ-aminolevulinic acid concentrations and haematological parameters of road sweepers working in congested areas of Bangkok. Journal of Nutritional and Environmental Medicine 1999; 9: 109–14

Janssen N.A.H., Schwartz J., Zanobetti A., and Suh H.H. Air Conditioning and Source-Specific Particles as Modifiers of the Effect of PM10 on Hospital Admissions for Heart and Lung Disease. Environ Health Perspect 2002; 110: 43–9

Jo W.K., and Yu C.H. Public Bus and Taxicab Drivers' Exposure to Aromatic Work-Time Volatile Organic Compounds. Environmental Research Section A 2001; 86: 66–72

Jo W.K., and Song K.B. Exposure to volatile organic compounds for individuals with occupations associated with potential exposure to motor vehicle exhaust and/or gasoline vapor emissions. The Science of the Total Environment 2001; 269: 25–37

Klimont Z., Cofala J., Schöpp W., Amann M., Streets D.G., Ichikawa Y., et al. Projections of SO2, NOx, NH3 and VOC emissions in East Asia up to 2030. Water, Air and Soil Pollution 2001; 130: 193–8

Kourtidis K.A., Ziomas I., Zerefos C., Kosmidis E., Symeonidis P., Christophilopoulos E., et al. Benzene, toluene, ozone, NO2 and SO2 measurements in an urban street canyon in Thessaloniki, Greece. Atmospheric Environment 2002; 36: 5355–64

Kousa A., L. Oglesby, K. Koistinen, N. Künzli, and M. Jantunen. Exposure chain of urban air $PM_{2.5}$—associations between ambient fixed site, residential outdoor, indoor, workplace and personal exposures in four European cities in the EXPOLIS-study. Atmospheric Environment 2002; 36: 3031–9

Kukkonen J., Valkonen E., and Walden J., Koskentalo T., Karppinen A., Berkowicz R., et al. Measurements and modeling of air pollution in a street canyon in Helsinki. Environmental Monitoring and Assessment 2000; 65: 371–9

Kulkarni M.M., and Patil R.S. Monitoring of daily integrated exposure of outdoor workers to respirable particulate matter in an urban region of India. Environmental Monitoring and Assessment 1999; 56: 129–46

Kuo C.Y., Hsu Y.W., and Lee H.S. Study of Human Exposure to Particulate PAHs Using Personal Air Samplers. Arch. Environ. Contam. Toxicol. 2003; 44: 454–459

Laden F., Neas L.M., Dockery D.W., and Schwartz J. Association of Fine Particulate Matter from Different Sources with Daily Mortality in Six U.S. Cities. Environ Health Perspect 2000; 108: 941–7

Lau W.L., and Chan L.Y. Commuter exposure to aromatic VOCs in public transportation modes in Hong Kong. The Science of the Total Environment 2003; 308: 143–55

Lee J.T., Kim H., Hong Y.C., Kwon H.J., Schwartz J., and Christiani D.C. Air Pollution and Daily Mortality in Seven Major Cities of Korea, 1991—1997. Environmental Research Section A 2000; 84: 247–54

Leong S.T., Muttamara S., and Laortanakul P. Evaluation of air pollution burden from contribution of motorcycle emission in Bangkok. Water, Air, and Soil Pollution 2001; 131: 41–60

Levy J.I., Houseman E.A., Spengler J.D., Loh P., and Ryan L. Fine Particulate Matter and Polycyclic Aromatic Hydrocarbon Concentration Patterns in Roxbury, Massachusetts: A Community-Based GIS Analysis. Environ Health Perspect 2001; 109: 341–347

Liard R., Zureik M., Moullec Y.L., Soussan D., Glorian M., Grimfeld A., et al. Use of personal passive samplers for measurements of NO2, NO, and O3 levels in panel studies. Environmental Research Section A 1999; 81: 339–48

Lin C.A., Pereira L.A.A., Nishioka D.C., Conceição G.M.S., Braga A.L.F., and Saldiva P.H.N. Air pollution and neonatal deaths in São Paulo, Brazil. Neonatal deaths and air pollution Brazilian Journal of Medical and Biological Research 2004; 37: 765–770

Lodovici M., Venturini M., Marini E., Grechi D., and Dolara P. Polycyclic aromatic hydrocarbons air levels in Florence, Italy, and their correlation with other air pollutants. Chemosphere 2003; 50: 377–382

Magari S.R., Schwartz J., Williams P.L., Hauser R., Smith T.J., and Christiani D.C. The Association Between Personal Measurements of Environmental Exposure to Particulates and Heart Rate Variability. Epidemiology 2002; 13: 305–310

Manning A.J., Nicholson K.J., Middleton D.R., and Rafferty S.C. Field study of wind and traffic to test a street canyon pollution model. Environmental Monitoring and Assessment 2000; 65: 283–313

Marr L.C., Grogan L.A ., Wöhrnschimmel H., Molina L.T ., and Molina M. J . Vehicle Traffic as a Source of Particulate Polycyclic Aromatic Hydrocarbon Exposure in the Mexico City Metropolitan Area. Environ. Sci. Technol.2004, 38,2584-2592

McConnell R., Berhane K., Gilliland F., London S.J., Islam T., Gauderman W.J., et al. Asthma in exercising children exposed to ozone: a cohort study. Lancet 2002; 359: 386–91

Miguel A.H., Eiguren-Fernandeza A., Jaquesa P.A., Froinesa J.R., Granta B.L., Mayo P.R., et al. Seasonal variation of the particle size distribution of polycyclic aromatic hydrocarbons and of major aerosol species in Claremont, California. Atmospheric Environment 2004; 38: 3241–3251

Mondal R., Sen G.K., Chatterjee M., Sen B.K., and Sen S. Ground-level concentration of nitrogen oxides (NOx) at some traffic intersection points in Calcutta. Atmospheric Environment 2000; 34: 629–33

Mukherjee A.K., Bhattacharya S.K., Ahmed S., Roy S.K., Roychowdhury A., and Sen S. Exposure of drivers and conductors to noise, heat, dust and volatile organic compounds in the state transport special buses of Kolkata city. Transportation Research Part D 2003; 8: 11–9

Naeher L.P., Holford T.R., Beckett W.S., Belanger K., Triche E.W., Bracken M.B**.,** et al. Healthy Women's PEF Variations with Ambient Summer Concentrations of PM_{10}, $PM_{2.5}$, SO_4^{2-}, H^+, and O_3. Am J Respir Crit Care Med 1999; 160: 117–25

O'Neill M.S., Ramirez-Aguilar M., Meneses-Gonzalez F., Hernández-Avila M., Geyh A.S., Sienra-Monge J.J., et al. Ozone Exposure among Mexico City Outdoor Workers. J. Air & Waste Manage. Assoc. 2003; 53: 339–346

O'Neill M.S., Loomis D., and Borja-Aburto V.H. Ozone, area social conditions, and mortality in Mexico City. Environmental Research 2004; 94: 234–42

Pankow J.F., Luo W., Bender D.A., Isabelle L.M., Hollingsworth J.S., Chen C., et al. Concentrations and co-occurrence correlations of 88 volatile organic compounds (VOCs) in the ambient air of 13 semi-rural to urban locations in the United States. Atmospheric Environment 2003; 37; 5023–46

Pfeifer G.D., Harrison R.M., and Lynam D.R. Personal exposures to airborne metals in London taxi drivers and office workers in 1995 and 1996. The Science of the Total Environment 1999; 235: 253–60

Preutthipan A., Udomsubpayakul U., Chaisupamongkollarp T., and Pentamwa P. Effect of PM10 pollution in Bangkok on Children with and without asthma. Pediatric Pulmonology 2004; 37: 187–92

Qi S., Yan J., Zhang G. Fu J., Sheng G., Wang Z., et al. Distribution of Polycyclic Aromatic Hydrocarbons in Aerosols and Dustfall in Macao. Environmental Monitoring and Assessment 2001; 72: 115–127

Reddy G.S., and Ruj B. Ambient air quality status in Raniganj-Asansol area, India. Environmental Monitoring and Assessment 2003; 89: 153–6

Riediker M., Williams R., Devlin R., Griggs T., and Bromberg P. Exposure to Particulate Matter, Volatile Organic Compounds, and Other Air Pollutants Inside Patrol Cars. Environ. Sci. Technol. 2003; 37: 2084–93

Romieu I., Lacasana M., McConnell R., and the Lead Research Group of the Pan-American Health Organization. Lead exposure in Latin America and the Caribbean. Environ Health Perspect 1997; 105: 398–405

Romieu I., Ramirez M., Maneses F., Ashley D., Lemire S., Colome S., et al. Environmental Exposure to Volatile Organic Compounds among Workers in Mexico City as Assessed by Personal Monitors and Blood Concentrations. Environ Health Perspect 1999; 107: 511–5

Ruchirawat M., Mahidol C., Tangjarukij C., Pui-ock S., Jensen O., Kampeerawipakorn O., et al. Exposure to genotoxins present in ambient air in Bangkok, Thailand — particle associated polycyclic aromatic hydrocarbons and biomarkers. The Science of the Total Environment 2002; 287: 121–132

Saarela K., Tirkkonen T., Laine-Ylijoki J., Juvelin J., Nieuwenhuijsen M.J., and Jantunen M. Exposure of population and microenvironmental distributions of volatile organic compound concentrations in the EXPOLIS study. Atmospheric Environment 2003; 37: 5563–75

Sánchez-Carrillo C.I., Cerón-Mireles P., Rojas-Martínez M.R., Mendoza-Alvarado L., Olaiz-Fernández G., and Borja-Aburto V.H. Surveillance of Acute Health Effects of Air Pollution in Mexico City. Epidemiology 2003; 14: 536–544

Satsangi G.S., Lakhani A., Kulshrestha P.R., and Taneja A. Seasonal and diurnal variation of surface ozone and a preliminary analysis of exceedance of its critical levels at a semi-arid site in India. Journal of Atmospheric Chemistry 2004; 47: 271–86

Sharma R., and Pervez S. Enrichment and exposure of particulate lead in a traffic environment in India. Environmental Geochemistry and Health 2003; 25: 297–306

Shendell D.G., and Naeher L.P. A pilot study to assess ground-level ambient air concentrations of fine particles and carbon monoxide in urban Guatemala. Environmental International 2002; 28: 375–382

Singer B.C., Hodgson A.T., Hotchi T., and Kim J.J. Passive measurement of nitrogen oxides to assess traffic-related pollutant exposure for the East Bay Children's Respiratory Health Study. Atmospheric Environment 2004; 38: 393–403

Šišovic A., Škrbec A., Vadjić V., Kalinić N., and Hršak J. PAH levels and profiles in the suspended particulate matter in Zagreb throughout four seasons. Environmental Monitoring and Assessment 2002; 74: 217–24

Smichowski P., Gómez D.R., Dawidowski L.E., Giné M.F., Bellato A.C.S., and Reich S.L. Monitoring trace metals in urban aerosols from Buenos Aires City. Determination by plasma-based techniques. Journal of Environmental Monitoring 2004; 6: 286–94

Son B., Yang W., Breysse P., Chung T., and Lee Y. Estimation of occupational and nonoccupational nitrogen dioxide exposure for Korean taxi drivers using a microenvironmental model. Environmental Research 2004; 94: 291–6

Suresh Y., Sailaja Devi M.M., Manjari V., and Das U.N. Oxidant stress, antioxidants, and nitric oxide in traffic police of Hyderabad, India. Environmental Pollution 2000; 109: 321–5

Szaniszló J., and Ungváry G. Polycyclic aromatic hydrocarbon exposure and burden of outdoor workers in Budapest. Journal of Toxicology and Environmental Health 2001; 62: 297–306

Ta W., Wang T., Xiao H., Zhu X., and Xiao Z. Gaseous and particulate air pollution in the Lanzhou Valley, China. Science of the Total Environment 2004; 320: 163–176

Tripathi R.M., Raghunath R., Kumar A.V., Sastry V.N., and Sadasivan S.. Atmospheric and children's blood lead as indicators of vehicular traffic and other emission sources in Mumbai, India. The Science of the Total Environment2001; 267: 1011–08

Tsai S.S., and Huang C.H. Relationship between air pollution and daily mortality in a tropical city: Kaohsiung, Taiwan. Journal of Toxicology and Environmental Health Part A 2003; 66: 1341–9

Upmanis H., Eliasson I., and Andersson-Sköld Y. Case studies of the spatial variation of benzene and toluene concentrations in parks and adjacent built-up areas. Water, Air and Soil Pollution 2001; 129: 61–81

U.S. Environmental Protection Agency. 2001. Review of the National Ambient Air Quality Standards for Particulate Matter: Policy assessment of scientific and technical information—OAQPS staff paper, Preliminary Draft, Office of Air Quality Planning and Standards, Research Triangle Park, NC. http://www.epa.gov/ttn/oarpg/t1sp.html

U.S. Department of Labor. Occupational Safety and Health Administration. Regulations (Standards - 29 CFR) 1910 Subpart Z - Toxic and Hazardous Substances. http://www.osha.gov/pls/oshaweb/owastand.display_standard_group?p_toc_level=1&p_part_number=1910

Venegas L.E., and Mazzeo N.A. Carbon monoxide concentration in a canyon of Buenos Aires City (Argentina). Environmental Monitoring and Assessment 2000; 65: 417–24

Verma D.K., and Tombe K.D. Benzene in Gasoline and Crude Oil: Occupational and Environmental Implications. AIHA Journal 2002; 63: 225–230

Von Schirnding Y.E.R., and Fuggle R.F. A study of the distribution of urban environmental lead levels in Cape Town, South Africa. The Science of the Total Environment 1996; 187: 1–8

Wang G., Wang H., Yu Y., Gao S., Feng J., Gao S., et al. Chemical characterization of water-soluble components of PM_{10} and $PM_{2.5}$ atmospheric aerosols in five locations of Nanjing, China. Atmospheric Environment 2003; 37: 2893–902

Wang X.M., Sheng G.Y., Fu J.M., Chan C.Y., Lee S.C., Chan L.Y., et al. Urban roadside aromatic hydrocarbons in three cities of the Pearl River Delta, People's Republic of China. Atmospheric Environment 2002; 36: 5141–8

WHO. 2001. Guidelines for Air Quality, WHO, Geneva, 2000.

Wilhelm M., and Ritz B. Residential Proximity to Traffic and Adverse Birth Outcomes in Los Angeles County, California, 1994–1996. Environ Health Perspect 2003; 111: 207–16

Wróbel A., Rokita E., and Maenhaut W. Transport of traffic-related aerosols in urban areas. The Science of The Total Environment 2000; 257: 199–211

Wu H.W.Y., and Chan L.Y. Surface ozone trends in Hong Kong in 1985–1995. Environment International 2001; 26: 213–222

Yang K.L. Spatial and seasonal variation of PM10 mass concentrations in Taiwan. Atmospheric Environment 2002; 36: 3403–11

Zagury E., Moullec Y.L., and Momas I. Exposure of Paris taxi drivers to automobile air pollutants within their vehicles. Occupational and Environmental Medicine 2000; 57: 406–10

Zheng J., Tan M., Shibata Y., Tanaka A., Li Y., Zhang G., et al. Characteristics of lead isotope ratios and elemental concentrations in PM10 fraction of airborne particulate matter in Shanghai after the phase-out of leaded gasoline. Atmospheric Environment 2004; 38: 1191–200

CHAPTER 3

A PRELIMINARY STUDY ON TRAFFIC-RELATED OCCUPATIONAL EXPOSURES TO $PM_{2.5}$, CO, AND VOCS IN TRUJILLO, PERU [1,2,3,4]

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ABSTRACT

Traffic-related air pollution is an increasing concern in urban areas in most of the countries in the world. A traffic-related personal exposure study was done among 58 workers (bus drivers, combi drivers, taxi drivers, street vendors, newspaper vendors, traffic police, and gas station attendants) and 10 office workers as controls, in Trujillo, Peru in July 2002. Airborne particulates with a diameter less than 2.5 microns ($PM_{2.5}$) were collected using an SKC pump with a flow rate of 4.0 L/min and BGI KTL Cyclone and Teflon-coated glass fiber filter with 2.0 μm pore size and 37 mm diameter. Carbon monoxide (CO) was measured by Pac III electrochemical sensors and Draeger stain tubes. Volatile organic compounds (VOCs) were sampled using Tenax-packed Perkin-Elmer diffusion tubes and quantified by a gas chromatograph coupled with mass spectrometer (GC-MS). The CO exposure (Mean=11.4 ppm; SD=8.9 ppm) measured by stain tubes among the four newspaper vendors is higher than the WHO 8-hour standard and USEPA 8-hour standard. The $PM_{2.5}$ TWA (with an average sampling duration of 7.7 hrs) exposures among the groups in our study ranged from the lowest exposure among gas station attendants (Mean±SD=64±26 $\mu g/m^3$) and office workers (65.2±8.5 $\mu g/m^3$) to the highest exposure among bus drivers (161±63 $\mu g/m^3$). VOC concentrations among different groups were quite variable, with average benzene and toluene exposures ranging from 5.48 and 22 $\mu g/m^3$ for combi drivers to 139 and 500 $\mu g/m^3$ for bus drivers respectively. In addition, smoking subjects had higher exposures to CO and BTEX (benzene, toluene, ethylbenzene, and xylene) than non-smokers, though the differences are not statistically significant. This preliminary study suggests that the traffic-related exposures investigated are of occupational health concern and thus merit larger exposure assessment and health-effects investigations.

Keywords air pollution, personal exposure, carbon monoxide, $PM_{2.5}$, VOCs, traffic-related

INTRODUCTION

Air pollution and its public health impacts are drawing increasing concerns from the environmental health research community, environmental regulatory agencies, industries, as well as the public. The

quality of the air, both indoors and outdoors, is closely related to morbidity and mortality from respiratory and cardiovascular diseases. Common air pollutants that draw intense concerns include particulate matter, ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, lead, and volatile organic compounds.

Dockery et al.[1] related excess daily mortality to several air pollutants, especially fine particulate matter (particulate matter with aerodynamic diameter of equal to or less than 2.5 microns, $PM_{2.5}$). Since then, many epidemiological studies on the adverse human effects of air pollutants have been conducted, and the effects ranged from variations in physiological functions and subclinical symptoms (heart rate, peak expiratory flow rate, etc.) to manifest clinical diseases (asthma, chronic obstructive pulmonary disease, stroke, lung cancer, leukemia, etc.), premature births and deaths[2–10].

Traffic-related particulates have been under intensive scrutiny for at least two reasons. One is due to the evidence that particulates generated from combustion processes, especially diesel exhaust particulates (DEP), are more potent in posing adverse health effects than those from non-combustion process[4,6]. Another reason is that traffic-generated emissions account for a significant portion of the total emissions of particulate matter in the urban areas in the industrialized countries. Further, many cities in the developing world are facing serious problems from traffic-related particulate emissions[11-13]. The United Nations estimates that over 600 million people in urban areas worldwide are exposed to dangerous levels of traffic-generated air pollutants[14].

Airborne particulate pollution is more serious in the developing world[15–17] but studies on exposure assessment and heath impacts of particulates, especially $PM_{2.5}$, are scarce in these areas. In-depth investigations on exposure assessment and health-effects of fine particulate are generally lacking. Studies showed that many developing countries are also facing serious CO pollution [12,18]. Volatile organic compounds (VOCs) are a class of pollutants sharing the same characteristic of high volatility in the ambient environment. Since benzene has been widely recognized as a human carcinogen (IARC, 2002) and some of the others also possess high toxicity, especially to central nervous system in humans [19], this group of traffic-related VOCs has received much concern in exposure assessment studies[20–26]. Nitrogen dioxide (NO_2), one of the main traffic-related air pollutants and precursors for the formation of

photochemical smog (together with VOCs) and ground-level ozone, is also under intensive investigation[27–30].

Despite the effort that has been made by epidemiologists from all over the world, health effects studies of particulate matter and gaseous air pollutants have been limited by the difficulties in the exposure assessment component of these studies. Several studies have shown that ambient levels of air pollutants were poor predictors of personal exposures[31–33], a conclusion that is not surprising when one considers the many microenvironments people spend time in during the course of their daily life, including work. An alternative for this is the adoption of traffic indicators (population density and traffic intensity) and geographic information system[34,35], which are perhaps suitable for long-term exposure assessment for large populations in urban areas. But they are still not sufficient to replace real personal exposures.

The introduction of portable measuring equipment made personal exposure assessment feasible. One advantage of it is its ability to directly measure personal exposure which is the very need in rigorous epidemiologic studies. The second strength is that it can be used to address exposure issues for high risk populations. One study showed that even microenvironmental monitoring cannot substitute for personal exposure[36]. Therefore, even for people who are typically less mobile than drivers or traffic policemen, a portable sampler is also an important tool in assessing their personal exposure levels.

Though in-depth exposure studies in the developing world are in urgent need, the volume of such studies is much smaller compared with such studies that have been performed in the developed countries, which is partly due to limited resources in these developing countries. Exposure assessment and epidemiologic studies in the developing world, however, are important and have several advantages. Firstly, increasing exposure data of traffic-related air pollution will provide scientific basis for pollution control in local areas. Furthermore, in-depth human health studies in these countries are necessary for assessing the magnitude of public health problems and setting priorities in environmental control planning. In addition, epidemiologic investigations in regions with different metrological and socioeconomic

backgrounds are helpful in strengthening scientific evidence about the associations or causative relationships between these traffic-generated pollutants and various health endpoints.

Toward this end, in July 2002, we conducted a pilot study in Trujillo, Peru, investigating personal occupational exposures to fine particulates ($PM_{2.5}$), CO and a wide spectrum of VOCs among a cohort of subjects including bus drivers, taxi drivers, combi drivers, gas station attendants, street vendors, newspaper vendors, traffic policemen, and office workers. The findings from this study will assist in the assessment of local air pollutant exposure profiles and their public health impacts and will be useful in the development of traffic-related air pollution epidemiologic studies in the study region. Data from these studies also add to the currently scarce findings on traffic-related air pollution and potential human health consequences in the developing world.

METHODS

Study Population

With the help of Trujillo City Hall, 58 workers exposed to city traffic were recruited and their exposures to traffic-related air pollutants ($PM_{2.5}$, CO, and VOCs) were studied in Trujillo, Peru in July 2002. The exposures of these pollutants among 10 office workers were also studied as the control group. These office workers work in buildings that are not adjacent to main streets where heavy traffic occurs. The occupational group of 58 workers includes 26 drivers (8 bus drivers, 8 combi drivers, and 10 taxi drivers), 8 street vendors (4 newspaper vendors and 4 other vendors), 6 traffic policemen and 18 gas station attendants. All the subjects were males. We expect these groups of people to have high and different traffic-related exposures since their working places are either directly in the streets (drivers and policemen), on roadside (vendors), or in locations where high exposures to both gas vapor and vehicle exhaust are likely (gas station attendants). Workers were studied for their full shifts, which ranged from 6–14 hrs. The exposure measurement was performed for each subject for one day only. Due to logistic limitations, we measured exposures for a subset of participants each day and thus our study lasted from

July 2 to July 13. Humidity and temperature data were recorded. During the study period, there was no precipitation.

Before the shift, the study was explained to each subject and consent forms were signed by each participant. A brief questionnaire was administered to each of them. Basic information such as age, occupation, residence, education, income, smoking, household stove type, and self-reported traffic density was included in the questionnaire. Personal air sampling began when the work shift began. At the end of the shift, personal air sampling was stopped and a time activity diary questionnaire was administered to each subject to record their activities and the duration of each activity during the full work shift.

$PM_{2.5}$ Sampling

To measure $PM_{2.5}$ exposure, portable samplers with SKC pumps at 4.0 L/min (SKC, Waltham, MA), BGI KTL Cyclones (BGI, Waltham, MA), and Teflon-coated glass fiber filter with 2.0 μm pore size and 37 mm diameter were used (Omega, Chelmsford, MA). Filters were properly labeled. Before and after sampling, the flow rate of the pumps was calibrated using an SKC calibrator. Immediately before each shift, the sampler was attached to the front of the subject' shirt (breathing zone). Each subject was told to pay attention to anything unusual with the sampler during the whole work shift.

At the end of the shift, $PM_{2.5}$ samples and field blanks were collected, put in boxes, sealed, and refrigerated. The total sampling time ranged from 6 to 14 hours, with an average of 7.7 hours. They were later brought back to a partially climate-controlled room for analysis in the Department of Environmental Health Science, University of Georgia.

For each filter, two pre-weights and two post-weights were performed. Before calculating the average, all the weights were adjusted according to specific temperature, humidity, and barometric pressure. The sampling volume was obtained by multiplying sampling time (in minutes) and the average of on flow rate and off flow rate (in L/min). $PM_{2.5}$ concentration was calculated as the weight difference between the filter pre-weights and the post-weights after adjusting for field blank and divided by the sampling volume. Damaged or overloaded filters were carefully described and recorded.

CO Sampling

Two methods were used for CO exposure measurement. Draeger Color Stain Diffusion Tube (AFC International, DeMotte, IN) was adopted for the exposure measurement for all the subjects. A real-time Draeger CO electrochemical sensor (Pac III E) with datalogger (AFC International, DeMotte, IN) was used among a subset of subjects (45 in total, including 8 bus drivers, 7 combi drivers, 5 taxi drivers, 5 traffic policemen, 10 gas station attendants, and 10 office workers).

The Draeger diffusion tube is a direct reading, scaled tube that can be used to determine the time weighted average (TWA) concentrations of CO with limits of detection ranging 6–600 ppm. It works by passive gaseous diffusion. For a TWA reading, simply determine the point where the stain length ends and divide this reading by the total length of sampling time. It was attached on the lapel of the subjects during field sampling.

Pac sensor measures CO concentration by sensing the change of potential from CO oxidation in the sampler. The real-time monitor for measuring CO gives a time-weighted data point every 15 seconds with detection limits of 0–2000 ppm. The data were stored in a datalogger that can be easily transferred to a laptop computer. Hourly and daily average concentrations were obtained from original values for statistical analysis. The instruments were calibrated with a CO calibration gas before and after the study and they were zeroed each sampling day in the field in a low CO environment. The samplers were installed at the waistline of the subjects during sampling.

VOC Sampling

Perkin-Elmer diffusion (passive) stainless steel tubes (90mm long, 6.3mm OD and 5mm ID) were used to collect VOC samples[37, 38]. Tenax™ TA (60/80 mesh, 200 mg) was packed in each tube as a thermal desorbable adsorbent. Before packing the tube, Tenax was preconditioned by heating in an inert atmosphere at 250°C for 16 h. The sorbent was retained in the tube by stainless steel gauzes. Prior to use, tubes was conditioned by heating slowly under inert carrier gas to 250°C and kept at this temperature for

10 min. Test was done to make sure that the thermal desorption blank was acceptably small, i.e., no greater than the equivalent of 10 ng for any of the calibration compounds.

Each Tenax tube had two end caps. Tubes were properly marked about 10 mm from one end. Immediately before the sampling, the sealing end cap (a closed metal end cap with PTFE seal) of the tube was replaced by a diffusive end cap with an opening to allow the ingress of vapors. The size of the opening in the diffusive end cap was the same as that of the ID of the tube (5mm). The tube was attached to the lapel of each subject with the opening end of the tube downward and the sampling lasted during the whole work shift. Field blanks were also prepared and put in the same place without opening the end cap of the tubes. Actually, tubes for field blank use and their handling were entirely the same as sampling tubes during the whole sampling process except that they did not really open to ambient air and take samples. These blanks were also labeled.

At the end of each work shift, the tube was taken off from the lapel of the subject, the diffusive end cap was replaced by the closed end cap, and the tubes were stored in an airtight container. During the whole field study, measures were taken to make sure that the tubes were not contaminated and the analytes were not lost.

Samples were taken back to the University of Georgia. Samples were analyzed at the Georgia Tech Research Institute. Samples were analyzed using an automated thermal desorption system (ATD400) coupled to a gas chromatograph with a mass spectrometer (GC-MS). Tubes to be desorbed were placed in the thermal desorption system where they were heated at 250°C and simultaneously purged with helium for 5 min. The sample in the carrier gas was concentrated by using a cold trap (low -30°C and high 300°C) containing 40 mg of Tenax TA. The sample was then transferred to a capillary column along a transfer line at 150°C. The chromatographic column used here was a 50 m × 0.22 mm fused silica column with thick-film BP-10 stationary phase. The temperature of the column was held at 10°C for 10 min and then was increased from 50°C to 250°C at a rate of 5°C/min. The concentration of VOCs in the sample was

determined by comparing the masses the sample analytes with those obtained from analyzing standard solutions of the corresponding analytes.

Diffusive sampling is an alternative to pumped sampling in recent years and has since become a reliable means in exposure assessment study. Compared with pumped (active) sampling, this diffusive sampling method has the advantage of lighter weight and lower cost and it is more acceptable among subjects. In addition, less training is required to perform diffusive sampling. Unlike active sampling, diffusion tubes give time-weighted average of the VOC exposure, instead of instantaneous or short-term fluctuations in VOC concentrations.

Statistical Analysis

All the datasets were manipulated in Microsoft® Excel 2002 first and were exported into SPSS 12.0 for all the statistical analysis including descriptive analysis, t-test, non-parametric test, and one-way ANOVA for the comparisons between exposures of different groups. The significant level for all statistical procedures used in the analysis was 0.05, if not mentioned specially. Normality test was performed on the pollutant data to decide whether the data need to be transformed. Data were log-transformed in order to use t-test and ANOVA.

One-way ANOVA, a robust method to normality assumption but requires symmetry of the data, [39] was adopted in the statistical analysis for all the exposure data by groups. Post hoc tests were used to test pairwise differences among group means when ANOVA suggested overall significant difference for an exposure across several groups. Before choosing types of post hoc tests, homogeneity of variance test (Levene Statistic) was adopted to see if the variance was homogenous across the groups. Student-Newman-Keuls and Duncan tests were chosen when the variance was homogenous. Otherwise, Tamhane and Dunnett T3 tests were performed.

RESULTS

The distributions of the pollutant concentrations

Based on histograms and Shapiro-Wilk test for normality (not shown here), it was found that none of these pollutant concentrations (CO, $PM_{2.5}$, and BTEX) were normally distributed. Therefore, all the

pollutant variables were transformed by taking logarithms (base 10). Many groups were still not normal after log-transformation, but most of them had improved skewnesses (ranging between -1 and 1) that were acceptable for one-way ANOVA.

Descriptive Analysis and comparisons of the pollutant concentrations

Descriptive statistics for CO exposures were summarized in Tables I. On average, gas station attendants (Mean±SD: 64.9±40.8 ppm; 95% CI: 35.74–94.06 ppm) and traffic policemen (Mean±SD: 32.6±17.3 ppm; 95% CI: 11.07 54.13 ppm) had high 15-sec TWA maximum CO exposure measured by chemical sensors while the control group office workers had the lowest CO exposure (Mean±SD: 7.1±4.3 ppm; 95% CI: 4.04–10.16 ppm). One-way ANOVA and post hoc tests on the log-transformed data indicated that office workers (the controls) had significantly lower levels of 15-sec CO TWA exposure than all the other groups except bus drivers. Gas station attendants were the highest exposure group for 15-sec CO by chemical sensors which was significantly different from all other exposure groups except traffic policemen.

For 15-min TWA maximum levels measured by chemical sensors (Table I), gas station attendants and traffic policemen consistently had significantly higher exposures than office workers and bus drivers. The exposure profile for maximum 1-hour TWA of CO measured by chemical sensors among the groups is roughly the same as 15-sec and 15-min CO (Table I), gas station attendants (Mean±SD: 4.0±3.4 ppm; 95% CI: 1.644–6.4543 ppm) were exposed to significantly higher 1-hour TWA CO concentration than office workers (Mean±SD: 0.6±0.4 ppm; 95% CI: 0.255–0.891 ppm) (p=0.039 in Tamhane Test and p=0.033 in Dunnett T3 Test). Traffic police were also a more highly exposed group (Mean±SD: 4.8±2.9 ppm; 95% CI: 1.261–8.347 ppm) compared to controls, but the difference was only marginally significant (p=0.102 in Tamhane Test and 0.061 in Dunnett T3 Test). Gas station attendants (Mean±SD: 2.3±2.1 ppm; 95% CI: 0.749–3.785 ppm) were exposed to significantly higher full shift TWA CO concentrations than office workers (Mean±SD: 0.1±0.1 ppm; 95% CI: 0.031–0.159 ppm). Traffic police (Mean±SD: 2.8±1.6

ppm; 95% CI: 0.811–4.825 ppm) were also a highly exposed group compared to controls but the difference was only marginally significant ($0.05<p<0.10$ in the two post hoc tests) (Figure 1).

Newspaper vendors had the highest exposure to CO measured by diffusion tube (Mean±SD: 11.4±8.9 ppm; 95% CI: -2.771–25.651 ppm) (Table I). Diffusion tube method gave similar pattern of exposures to chemical sensor method, as was evidenced in Table I, with gas station attendants (Mean±SD: 4.78±1.96 ppm; 95% CI: 3.802–5.754 ppm) and traffic policemen (Mean±SD: 3.76± 1.86 ppm; 95% CI: 1.802–5.714 ppm) being more highly exposed to CO than all the other groups except newspaper vendors (Figure 2). Office workers as controls had the lowest exposure on average (Mean±SD: 2.05±1.75 ppm; 95% CI: 0.798–3.298 ppm). ANOVA and post hoc tests showed, however, that gas station attendants had significantly higher exposure than bus drivers but not than office workers, all the other groups not being significantly different. The reason may be that the big variance in office worker exposures was considered in the analysis when homogeneity of variances was not assumed. The high exposures among newspaper vendors were not significant in the analysis which may have been affected by the small sample size.

Unlike the CO exposure profile, $PM_{2.5}$ exposures among bus drivers (Mean±SD: 161±63.4 $\mu g/m^3$; 95% CI: 3.390–318.529 $\mu g/m^3$) and combi drivers (Mean±SD: 114±26.9 $\mu g/m^3$; 95% CI: 81.071–147.839 $\mu g/m^3$) are higher than those among other groups (Table II). Both office workers (Mean±SD: 65±8.5 $\mu g/m^3$; 95% CI: 54.663–75.756 $\mu g/m^3$) and gas station attendants (Mean±SD: 64±26.5 $\mu g/m^3$; 95% CI: 45.055–82.958 $\mu g/m^3$) were exposed to lower levels of $PM_{2.5}$ (Figure 3). Bus drivers were exposed to higher level of $PM_{2.5}$ than gas station attendants (P=0.010) and office workers (P=0.004). Once again, small sample sizes may explain the insignificant differences among the other groups.

One-way ANOVA and post hoc tests demonstrated significantly higher exposures of benzene among bus drivers (Mean±SD: 139±113$\mu g/m^3$; 95% CI: -41.156–318.264 $\mu g/m^3$) and gas station attendants (Mean±SD: 111±118$\mu g/m^3$; 95% CI: 47.529–173.705 $\mu g/m^3$) than combi drivers (Mean±SD: 5.5±1.7$\mu g/m^3$; 95% CI: 2.707–8.260 $\mu g/m^3$) and taxi drivers (Mean±SD: 8.4±3.5$\mu g/m^3$; 95% CI: 5.674–11.034 $\mu g/m^3$) (Table III). One gas station attendant had the highest exposure of benzene (470 $\mu g/m^3$).

Because only one traffic policeman participated, his data was not included in the analysis. Bus drivers (Mean±SD: 500±441 μg/m^3; 95% CI: -47.619–1046.745 μg/m^3) had the highest exposure of toluene followed by gas station attendants (Mean±SD: 254±226 μg/m^3; 95% CI: 128.717–378.989 μg/m^3), if not considering the only traffic policeman and the office worker. Benzene exposure levels of bus drivers and gas station attendants were significantly higher than those of combi drivers and taxi drivers. The highest ethylbenzene and xylene exposure group was gas station attendants (Mean±SD: 43.2±40.1 and 213.6±197.3 μg/m^3 respectively) (P=0.000 in comparison with both combi and taxi drivers for both the pollutants). The exposure levels of BTEX among combi driver and taxi driver groups could not be distinguished from each other in the ANOVA analysis. The three isomers of xylene had the same pattern of exposures among the three groups, with gas station attendants being the highest exposure group (Mean±SD: 110.1±110.5, 52.2±57.3, and 52.2±33.8 μg/m^3 for m-, o-, and p-xylene respectively) (Table IV).

Gas station attendants had the highest exposures to BTEX, compared to the other two groups (Figure 4). Several groups were not considered in this comparison because not all the BTEX data were available for them. Descriptive statistics for other VOCs are summarized in Table V-(A-C). In general, gas station attendants had significantly higher exposures to these VOCs than combi drivers and taxi drivers (P<0.05 in 39 Mann-Whitney tests in a total of 48 tests).

Comparison between the two CO measuring methods

Comparisons between the two CO measuring methods, stain tube method and chemical sensor method, were performed. Though both the Pearson or Spearman correlations were highly significant, the two correlation coefficients (0.384 and 0.329 respectively) were rather low, indicating that the two methods did not give consistent results in the study.

Taking the column of CO values from chemical sensor method as dependent variable and that of stain tube method as independent, simple linear regression (intercept=0.015, slope=0.337, and p value=0.009) showed that the results from the two methods were drastically different from each other. In

the equation, the intercept is largely negligible compared with the measuring values. Regression without intercept showed that, on average, chemical sensor gave values 34% of those from stain tube method.

Correlations between pollutants

Both Pearson correlations and Spearman correlations were calculated between the air pollutants. The correlations between $PM_{2.5}$, CO measured by stain tubes (CO-Tube), CO measured by chemical sensors (CO-Sensor) and BTEX were not high, but the correlations between the four main VOCs (BTEX) were very high, indicating that they probably come mainly from common sources, as have been expected.

B/T/E/X ratios

Based on arithmetic means, the overall B/T/E/X ratio was calculated to be 1.0/2.8/0.3/1.5. The ratios for combi drivers, taxi drivers, and gas station attendants were 1.0/4.1/0.5/2.9, 1.0/4.5/0.6/3.3, and 1.0/2.3/0.4/1.9 respectively, suggesting that combi drivers and taxi drivers were exposed to similar composition of BTEX while the BTEX exposures among gas station attendants may have additional sources. The overall ratio of m-, o-, and p-xylenes was 1.0/0.46/0.48. The ratios for combi drivers, taxi drivers, and gas station attendants were 1.0/0.44/0.48, 1.0/0.47/0.54, and 1.0/0.47/0.47 respectively, suggesting that the exposure profiles to xylene isomers among the three groups were roughly the same.

Factors influencing personal exposures to CO, $PM_{2.5}$ and VOCs

Age, education, self-reported traffic density and other factors surveyed in the questionnaire were also examined to see if these factors were associated with measured personal exposures. Due to small sample sizes, most of these factors did not show consistent patterns and thus did not warrant further examination. Among the factors, only smoking seems to be consistently related to personal exposures (Table VI). On average, exposure among the smokers is higher than non-smokers for CO and BTEX, but not for $PM_{2.5}$.

Both t-test and non-parametric test were performed on the transformed data. Though some of the tests did give marginal significance, all of these t-tests gave negative results at the significant level of 0.05. However, the largely consistent exposure pattern (except $PM_{2.5}$) and some marginal significant results were quite suggestive, considering the small sample sizes in the study.

Before exploring the relationship between smoking status and B/T/E/X ratio, a simple Chi-square test was performed to see if the percent of smokers among combi drivers and taxi drivers (as a single group) was significantly different from that among gas station attendants. No significant difference in the percent of smokers was found between the two groups (P=0.326). Therefore, occupation was not a confounder to smoking. So we were able to see if B/T/E/X ratio among smokers was the same as that among non-smokers.

Among the BTEX exposure groups, the BTEX ratio was 1.0/2.1/0.35/1.78 for the three smokers and 1.0/5.2/0.64/3.0 for the 15 nonsmokers, while the total ratio for the 18 subjects was 1.0/3.2/0.45/2.2. This suggested that smokers may be exposed to higher benzene level compared with other VOCs, in addition to the fact that smoking increases overall VOC exposures. Small sample sizes make this finding inconclusive.

DISCUSSION

Traditional means of exposure assessment rely heavily on a few fixed monitoring sites in a certain area, which have been showen to be a poor surrogate for real exposures among humans [31–33]. In this preliminary study, we used personal samplers to obtain personal exposures to CO, $PM_{2.5}$ and VOCs among several groups who were suspected high exposure subjects. Findings in this study suggested that the exposure levels of many of these pollutants were high enough to draw health concerns.

Carbon Monoxide

The average CO exposure measured by stain tubes among the four newspaper vendors was 11.4 ppm, which is higher than the WHO 8-hour standard of 8.7 ppm and USEPA 8-hour standard of 9 ppm. Due to the small sample size, we do not have high confidence to conclude that CO exposure among this group was significantly higher than these standards, however, it suggests that further study with larger numbers of subjects is warranted. Other groups in this study had exposure levels ranging between 2 and 4 ppm, which were much lower. In addition, the average levels of maximum 1-hour TWA of CO measured by chemical sensors among two groups (traffic police and gas station attendants) in our study exceeded 4 ppm. These exposures are not high, but they may still pose health threats to these groups of people, since

some epidemiologic studies have demonstrated that CO levels much lower than EPA standards were linked to elevated mortality and morbidity from many diseases[40,41].

In a time series analysis[40] on air pollution data and hospital admissions for congestive heart failure in Chicago, Illinois, US, it was found that an average ambient exposure of 2.509 ppm (1-hour maximum) of CO combined with low temperature had a consistent correlation with an increase in hospital admissions for the disease. Another population study in Nevada[41] linked a mean ambient CO exposure of 3.09 ppm (also 1-hour Maximum) to increased cardiovascular disease hospitalization. The data used in both the studies were fixed-site monitoring data, which may not be true indicators of personal exposures. In the Nevada study, other air pollutants were not measured. In addition, these studies only confirmed associations between CO ambient concentrations and health effects and they cannot prove that CO a causative factor. However, considering the low levels of CO in their studies, personal exposures of CO may be a concern in our study, if the meteorological conditions and pollution profiles on the days of measurement in our study is somewhat typical in Trujillo on yearly basis.

Comparisons were made between the findings in our study and those in other exposure studies carried out in European countries and the developing world (Table VII). CO personal exposures among most of the groups in our study were lower than those found in most of the other studies. In the Ankara study,[42] the ambient CO exposures claimed by the authors measured at several intersections can be considered to be personal exposures since the samplers were attached at the shoulder level on each traffic policeman. The Athens study[18] was actually carried out both in the summer and winter, but only winter values (which were more complete) were reported for comparison purpose.

In spring 1997, an exposure study was carried out in Paris among 28 randomly selected taxi drivers without environmental tobacco smoke (ETS) exposure using Pac II electrochemical samplers[43]. CO exposure in the diesel-fuelled vehicles (only one vehicle had gas-fuelled engine) during about an 8-hour period in the daytime among the subjects was 3.8 ppm, which was lower than the threshold value recommended by WHO but higher than the average exposure of full shift CO by Pac III chemical sensors among the four non-smoking taxi drivers in our study (0.785 ppm). This concentration was higher than

the average CO exposure level of the four non-smoking taxi drivers in our study (0.785 ppm). During a two-week period in March 1998, exposure to CO among school children during car traffic and walking was assessed in Northampton, UK.[44] Results showed that the exposure level during the commuting period ranged between 4 to 7 ppm for most cases. These personal exposure data were obtained using the same type of sampler, Draeger Pac III monitor, as in our study. However, the commuting time for the children in the UK study[44] was only 6–8 min, which had little effect on their Maximum 8-hour exposures. The short sampling time in their study makes it difficult to compare the findings between their study and ours.

In an exposure study in an urban area of Athens, Greece[18], in-vehicle environment CO was measured using electrochemical monitors. The exposure level in private cars was the highest (21.4 ppm in the summer) followed by those in buses and trolleys, which ranged from 8 to 11 ppm in either summer or winter. This microenvironmental monitoring data were somewhat comparable to the data in our study, especially to exposure data among drivers, since the drivers stayed in their vehicles most of the time during shift hours. Compared with their study, the CO levels measured by electrochemical sensors in our study were much lower. In another microenvironmental study in Guangzhou, China, CO levels measured in taxies and buses were 23.7 (28.7 for air-conditioned taxies) and 8.6 (8.9 for air-conditioned buses) ppm respectively[12]. In agreement with our study, bus drivers seem to be less exposed than taxi drivers. The samplers used in the Guangzhou study were also portable CO electrochemical monitors, which makes it easy for comparison.

Personal exposure levels of CO among 50 traffic policemen during their work shift in several intersections in Ankara [42] gave high levels of CO, with averages ranging from 6 to 24 ppm over about 8 hour's period (3 h to 12 h). An investigation in downtown Buenos Aires [45] found a high frequency of ambient 8-hour (8am to 4pm) CO levels (with an average of 10.2 ppm) that exceeded 9 ppm in a street canyon. North Carolina Highway Patrol troopers had a low level of in-car CO exposure (2.6 ppm) during their work shift.[46]

$PM_{2.5}$

The $PM_{2.5}$ TWA (with an average sampling duration of 7.7 hrs) exposures among the groups in our study ranged from the lowest exposure among gas station attendants (Mean=64 μg/m^3; SD=26 μg/m^3) and office workers (Mean=65.2 μg/m^3; SD=8.5 μg/m^3) to the highest exposure among bus drivers (Mean=161 μg/m^3; SD=63 μg/m^3). Though these values cannot be directly compared to EPA 24h standard of 65 μg/m^3, some epidemiological studies [47] have shown that these exposure levels may be harmful to occupational exposure subjects. In addition, if the findings in this study were true reflections of the $PM_{2.5}$ exposure profile among these groups, these exposure levels would have exceeded the EPA annual standard of 15 μg/m^3.

The exposure levels measured in our study seem to be higher than those obtained in several other studies. This was summarized in Table VIII. Generally speaking, $PM_{2.5}$ exposure assessment studies on personal exposure or in traffic microenvironment are still very scarce, though there have been some other studies on $PM_{3.5}$, $PM_{4.0}$, or PM_{10}[48]. The results of the latter studies are not listed here in Table VIII since it is difficult to make comparisons for these findings.

In September 1996, the 7-day consecutive time-weighted average exposures to $PM_{2.5}$ among 20 taxi drivers were measured in London, UK[49]. The TWA during the whole sampling period was found to range between 33.36–145 μg/m^3. This result cannot be directly compared with the findings in our study since the targeted exposure in our study was occupational by nature and therefore only lasted for about 8 hours on average. Transport microenvironmental exposures to $PM_{2.5}$ were measured using a specially designed portable high flow gravimetric samplers with a flow rate of 16 L/min in a London study [48]. The arithmetic means (geometric means) of $PM_{2.5}$ exposures during bus and car commuting in the summer were found to be 39 (33.4) and 37.7 (35) μg/m^3 respectively. These exposures were 38.9 (30.9) and 33.7 (23.7) μg/m^3 respectively in the winter. But the comparison with our findings is limited by the sampling duration in the London study which was much shorter than that in ours, though the sampling equipment was roughly the same.

In Raleigh, NC, US, 10 nonsmoking highway patrol troopers were measured for their in-car exposures to air pollutants during their late work shift and the average $PM_{2.5}$ exposure was 23 μg/m^3 [46].

In the Guangzhou study, [12] morning and evening peak hour (150 min for each) $PM_{2.5}$ exposures measured by DuskTrak real-time portable monitors in air-conditioned and non-air-conditioned buses were 101 and 145 μg/m^3 respectively, while these values were 73 and 106 μg/m^3 in air-conditioned and non-air-conditioned taxies respectively. Inconsistency had been found between these light-scattering equipments and gravimetric samplers, but the concentrations the authors reported in their study had been converted to high volume for comparison purpose. Compared with their findings, $PM_{2.5}$ exposures among the bus drivers we studied were higher. In May 2002, an exposure study in Mexico City gave rush hour (3h) exposures of $PM_{2.5}$ for three transport modes (minibus, bus, and metro), the arithmetic means (geometric means) of which were 68 (62), 71 (65), 61 (57) μg/m^3 respectively[13]. These results were lower than those in our study. The comparability of these three studies with our study are better than that of the two UK studies as sampling time is concerned, though the sampling durations and time of the day were not the same.

VOCs

VOC concentrations among different groups were quite different, with average benzene and toluene exposures ranging from 5.48 and 22 μg/m^3 for combi drivers to 139 and 500 μg/m^3 for bus drivers respectively. For BTEX, the exposures among gas station attendants (110.6/253.9/43.2/213.6 μg/m^3) were about 10 times higher than those of combi and taxi drivers combined together (7.5/32.7/4.0/23.9 μg/m^3). This was not really surprising, since gas station attendants stay in an environment with much more evaporation of VOCs than traffic vehicles. In other studies, similar results were found, some of which were listed in Table IX, a table to compare BTEX exposure data from different studies. Similar to our findings, a personal exposure measurement campaign carried out among service station attendants, street vendors, and office workers discovered that BTEX exposures among service station attendants were the highest (310/680/110/490 μg/m^3) [50].

BTEX exposures in this study were lower compared with OSHA occupational exposure limit of 3.19 for benzene, 754 for toluene and 434 mg/m3 for both ethylbenzene and xylene. But this does not

mean that exposures at these levels are safe, especially for benzene, a widely accepted human carcinogen with no threshold value to cause cancers.

Compared with VOC measurements in other studies (Table IX), the variances of VOC exposure values in our study were much higher, with low exposure groups in this study having lower VOC exposures and high exposure groups in this study having higher exposures than those in other studies. But it has been demonstrated in several studies that gas station attendants had much higher exposures of BTEX than other groups. [50-52]

A preliminary study carried out in Guangzhou, China [22] measuring in-vehicle BTEX exposures found that average BTEX levels in taxies (33.6/108.5/20.3/43.2 μg/m^3) were much higher than those in buses (12.4/56.4/8.3/17.5 μg/m^3). Another in-vehicle exposure measurement study in Hong Kong[23] found much lower BTEX levels than many studies carried out in Asia, US, and Europe, which may be partly due to different study design, sampling equipment, meteorological conditions, and gasoline compositions. These in-vehicle studies are not comparable to our personal exposure study.

In a Korean study, [53] median exposures to BTEX among smoking Korean bus drivers and taxi drivers were found to be 28.1/88.7/8.1/30.2 and 44/141/10.2/37.3 μg/m^3 respectively, which were significantly higher than those among non-smoking drivers, being 14.5/49.5/7.0/21.4 and 24.8/80.8/8.8/23.6 respectively. And BTEX exposures among taxi drivers were significantly higher than those among bus drivers. This was in agreement with the Guangzhou study. The study used the same sampling method as in ours, which makes it possible for the comparisons to our study. In another Korean study, [54] VOC exposures among 32 subjects working in roadside shoe stalls were measured and high average levels of benzene, toluene and xylene (BTX) were found in the indoor environment (732/6777/5382 μg/m^3). Since the ratio of these VOCs was quite different from that of outdoor VOCs, it was suspected that indoor sources may have played an important role in the total exposures. This indoor exposure cannot be compared with our findings, though the sampling duration was also 8 hours in their study. Jo et al.[51] found in a separate Korean study that occupational exposures to BTEX during working hours among traffic policemen, parking garage attendants, and gas station attendants were found to be

32.5/120/7.8/24.7, 31.4/125/9.9/32.7 and 78.3/134/12.5/42.9 μg/m^3 respectively. VOC exposures among gas station attendants were much higher, which was in agreement with the results in our study. In the city of Kolkata in India[55], occupational exposures to VOCs among 12 bus drivers were measured and were found to be much higher than those measured in other studies, the arithmetic means of benzene, toluene, o-xylene, and p-xylene were 527.3, 472.8, 1265.5 and 402.8 μg/m^3 respectively. But different sampling durations prevent a direct comparison with our findings.

The European Air Polllution Exposure Distributions (EXPOLIS) study mainly focused on air pollutant exposures among adult subjects who are representative of the general population. One such study in Helsinki[56] found much lower levels of personal exposures during 48 h sampling period of BTEX than those in our study. The arithmetic and geometric means of BTEX were 2.6/17.1/3.3/15.1 and 2.1/13.8/2.5/10.0 for non-ETS exposed group and 4.7/73.6/14.6/66.5 and 3.2/20.9/3.4/14.6 μg/m^3 for ETS exposed group respectively. The higher exposures among smokers were in agreement with the Korean study [53]. It must be noted that our study measured occupational exposures which only lasted for an average of about 8 hours, which cannot be surrogates for total daily exposures.

A benzene exposure study carried out in France[20] among 50 non-smoking citizens including 30 outdoor workers gave an average personal exposure of 10.3 μg/m^3 during working days, which exceeded the European mean annual exposure limit of 5 μg/m^3. In 1996, benzene exposures in catalyst-equipped and non-catalyst-equipped vehicles during morning peak hours in metropolitan area in Sidney, Australia were found to be 70.6 and 153.7 μg/m^3 respectively.[57] High exposures to benzene, toluene and xylenes were also measured in a personal measurement campaign carried out in two cities in Italy.[52] Among the three groups measured, petrol pump attendants (with summer BTX exposures of 503/712/379 μg/m^3 and winter BTX exposures of 161/568/285 μg/m^3) were exposed to higher levels of BTX than policemen and municipal employees during an 8-hour work duration. Unlikely that used in our study, chemical desorption method was adopted to extract samples in the Italian study. This difference may have some influence on the comparability of the two studies.

In Detroit, Michigan, US, [21] the VOC concentrations measured in traffic buses (4.5/10.2/9.0/2.1) and the ambient air along the bus routes during rush hours were found to be similar to several studies in Canada and Europe, but were lower than VOC exposures in cities in developing countries. The levels measured in the bus were similar to those measured outside the bus. Another US study also showed low levels of BTEX (4.0/10.4/0.9/4.5 μg/m^3) exposures among traffic policemen during their patrol shift in highways. [46]

The high correlation coefficients between BTEX in our study suggested that the VOC exposures among these groups may be mainly emitted from a common source, i.e., traffic. The differences of B/T/E/X ratios among combi drivers, taxi drivers, and gas station attendants may be explained by the fact that combi drivers and taxi drivers had actually two main sources of emission, gas evaporation and engine exhaust, while gas station attendants were more exposed to VOCs from evaporated gasoline. We do not have evidence about how much of the total exposure in the gas stations was from the traffic vehicles staying at the gas station for refueling.

It was interesting to note that smoking seemed to have played a role in CO, $PM_{2.5}$, and VOC exposures, with smokers having higher exposures to these pollutants. This was in agreement with the Finland study and two of the investigations in Korea (Table IX). Another intriguing finding was that smokers seemed to have a higher exposure to benzene compared with other VOC exposures. However, this trend was not consistent when examining the results from the other three studies (Table IX).

CONCUSIONS

In this pilot study, the CO exposure (11.4±8.9 ppm) measured by stain tubes among the four newspaper vendors is higher than the WHO 8-hour standard of 8.7 ppm and USEPA 8-hour standard of 9 ppm. The $PM_{2.5}$ TWA exposures among the groups in our study ranged from the lowest exposure among gas station attendants and office workers to the highest exposureamong bus drivers. VOC concentrations among different groups were quite different, with average benzene and toluene exposures ranging from 5.48 and 22 μg/m^3 for combi drivers to 139 and 500 μg/m^3 for bus drivers respectively. Another interesting finding was the higher exposures to all these pollutants among the smoking subjects.

This preliminary study suggested that many of these exposures (CO, $PM_{2.5}$, and benzene) as well as the repeatability of the two CO measuring methods in the study warrant further investigations. In future studies in the city, a balanced study design with larger sample sizes and longer study duration are needed to better characterize the exposure profile. In addition, a certain number of smokers are needed to quantify the contribution of smoking to the total personal exposures to these pollutants. If the influence of smoking is not an objective, smoking should be listed in exclusion criteria in choosing subjects.

ACKNOWLEDGEMENTS

Special thanks go to Meagan Kane, Krista Merry, and Kat Smith for their field study information, lab work, data input, or data interpretation assistance.

REFERENCES

1. **Dockery, D.W., C.A. Pope, X. Xu, J.D. Spengler, J.H. Ware, M.E. Fay, et al.:** An Association between Air Pollution and Mortality in Six U.S. Cities. *The New England Journal of Medicine 329*: 1753–1759 (1993)

2. **Delfino R.J., A.M. Murphy-Moulton, and M.R. Becklake:** Emergency room visits for respiratory illnesses among the elderly in Montreal: association with low level ozone exposure. *Environmental Research Section A 76*: 67–77 (1998)

3. **Naeher L.P., T.R. Holford, W.S. Beckett, K. Belanger, E.W. Triche, M.B. Bracken, et al:** Healthy Women's PEF Variations with Ambient Summer Concentrations of PM_{10}, $PM_{2.5}$, SO_4^{2-}, H^+, and O_3. *Am J Respir Crit Care Med 160*: 117–125 (1999)

4. **Laden F., L.M. Neas, D.W. Dockery, and J. Schwartz:** Association of Fine Particulate Matter from Different Sources with Daily Mortality in Six U.S. Cities. *Environ Health Perspect 108*: 941–947 (2000)

5. **Suresh Y., Sailaja M.M. Devi, V. Manjari, and U.N. Das:** Oxidant stress, antioxidants, and nitric oxide in traffic police of Hyderabad, India. *Environmental Pollution 109*: 321–325 (2000)

6. **Janssen N.A.H., J. Schwartz, A. Zanobetti, and H.H. Suh:** Air Conditioning and Source-Specific Particles as Modifiers of the Effect of PM10 on Hospital Admissions for Heart and Lung Disease. *Environ Health Perspect 110*: 43–49 (2002)

7. **Calderón-Garcidueñas L., A. Mora-Tiscareño, L.A. Fordham, G. Valencia-Salazar, C.J. Chung, A. Rodriguez-Alcaraz, et al:** Respiratory damage in children exposed to urban pollution. *Pediatric Pulmonology 36*: 148–161 (2003)

8. **Wilhelm, M., and B. Ritz:** Residential Proximity to Traffic and Adverse Birth Outcomes in Los Angeles County, California, 1994–1996. *Environ Health Perspect 111*: 207–216 (2003)

9. O'Neill M.S., D. Loomis, and V.H. Borja-Aburto: Ozone, area social conditions, and mortality in Mexico City. *Environmental Research 94*: 234–242 (2004)

10. Preutthipan A., U. Udomsubpayakul, T. Chaisupamongkollarp, and P. Pentamwa: Effect of PM10 pollution in Bangkok on Children with and without asthma. *Pediatric Pulmonology 37*: 187–192 (2004)

11. Yang, K.L.: Spatial and seasonal variation of PM_{10} mass concentrations in Taiwan. *Atmospheric Environment 36*: 3403–3411 (2002)

12. Chan, L.Y., W.L. Lau, S.C. Zou, Z.X. Cao, and S.C. Lai: Exposure level of carbon monoxide and respirable suspended particulate in public transportation modes while commuting in urban area of Guangzhou, China. *Atmospheric Environment 36*: 5831–5840 (2002)

13. Gómez-Perales, J.E., R.N. Colvile, M.J. Nieuwenhuijsen, A. Fernández-Bremauntz, V.J. Gutiérrez-Avedoy, V.H. Páramo-Figueroa, et al.: Commuters' exposure to $PM_{2.5}$, CO, and benzene in public transport in the metropolitan area of Mexico City. *Atmospheric Environment 38*: 1219–1229 (2004)

14. Cacciola, R.R., M. Sarva, and R. Polosa: Adverse respiratory effects and allergic susceptibility in relation to particulate air pollution: flirting with disaster. *Allergy* 57: 281–286 (2002)

15. Cohen, D.D., D. Garton, E. Stelcer, T. Wang, S. Poon, J. Kim, et al.: Characterisation of $PM_{2.5}$ and PM_{10} Fine Particle Pollution in Several Asian Regions. *16th Int. Clean Air Conf. Christchurch, NZ,* 18–22 Aug 2002

16. He, K., F. Yang, Y. Ma, Q. Zhang, X. Yao, C.K. Chan, et al.: The characterization of $PM_{2.5}$ in Beijing, China. *Atmospheric Environment 35*: 4959–4970 (2001)

17. Yao, X., A.P.S. Lau, M. Fang, C.K. Chan, and M. Hu: Size distributions and formation of ionic species in atmospheric particulate pollutants in Beijing, China: 2—dicarboxylic acids. *Atmospheric Environment 37*: 3001–3007 (2003)

18. Duci, A., A. Chaloulakou, and N. Spyrellis: Exposure to carbon monoxide in the Athens urban area during commuting. *The Science of the Total Environment 309*: 47–58 (2003)

19. Greenberg M.M.: The Central Nervous System and Exposure to Toluene: A Risk Characterization. *Environmental Research 72*: 1–7 (1997)

20. Gonzalez-Flesca, N., M.S. Bates, V. Delmas, and V. Cocheo: Benzene exposure assessment at indoor, outdoor, and personal levels. The French contribution to the life MACBETH programme. *Environmental Monitoring and Assessment 65*: 59–67 (2000)

21. Batterman, S.A., C.Y. Peng, and J. Braun: Levels and composition of volatile organic compounds on commuting routes in Detroit, Michigan. *Atmospheric Environment 36*: 6015–6030 (2002)

22. Chan, L.Y., W.L. Lau, X.M. Wang, and J.H. Tang: Preliminary measurements of aromatic VOCs in public transportation modes in Guangzhou, China. *Environment International 29*: 429–435 (2003)

23. Lau, W.L., and L.Y. Chan: Commuter exposure to aromatic VOCs in public transportation modes in Hong Kong. *The Science of the Total Environment 308*: 143–155 (2003)

24. Upmanis, H., I. Eliasson, and Y. Andersson-Sköld: Case studies of the spatial variation of benzene and toluene concentrations in parks and adjacent built-up areas. *Water, Air and Soil Pollution 129*: 61–81 (2001)

25. Carr, D., O. van Ehrenstein, S. Weiland, C. Wagner, O. Wellie, T. Nicholai, et al.: Modeling annual benzene, toluene, NO_2, and soot concentrations on the basis of road traffic characteristics. *Environmental Research Section A 90*: 111–118 (2002)

26. Kourtidis, K.A., I. Ziomas, C. Zerefos, E. Kosmidis, P. Symeonidis, E. Christophilopoulos, et al.: Benzene, toluene, ozone, NO_2 and SO_2 measurements in an urban street canyon in Thessaloniki, Greece. *Atmospheric Environment 36*: 5355–5364 (2002)

27. Singer, B.C., A.T. Hodgson, T. Hotchi, and J.J. Kim: Passive measurement of nitrogen oxides to assess traffic-related pollutant exposure for the East Bay Children's Respiratory Health Study. *Atmospheric Environment 38*: 393–403 (2004)

28. Gilbert, N.L., S. Woodhouse, D.M. Stieb, and J.R. Brook: Ambient nitrogen dioxide and distance from a major highway. *The Science of the Total Environment 312*: 43–46 (2003)

29. Reungoat, P., M. Chiron, S. Gauvin, Y.L. Moullec, and I. Momas: Assessment of exposure to traffic pollution using the ExTra index: study of validation. *Environmental Research 93*: 67–78 (2003)

30. Maruo, Y.Y., S. Ogawa, T. Ichino, N. Murao, and M Uchiyama: Measurement of local variations in atmospheric nitrogen dioxide levels in Sapporo, Japan, using a new method with high spatial and high temporal resolution. *Atmospheric Environment 37*: 1065–1074 (2003)

31. Liard, R., M. Zureik, Y.L. Moullec, D. Soussan, M. Glorian, A. Grimfeld, et al.: Use of personal passive samplers for measurements of NO2, NO, and O3 levels in panel studies. *Environmental Research Section A 81*: 339–348 (1999)

32. Kousa, A., L. Oglesby, K. Koistinen, N. Künzli, and M. Jantunen: Exposure chain of urban air $PM_{2.5}$—associations between ambient fixed site, residential outdoor, indoor, workplace and personal exposures in four European cities in the EXPOLIS-study. *Atmospheric Environment 36*: 3031–3039 (2002)

33. Adgate, J.L., G. Ramachandrana, G.C. Pratt, L.A. Waller, and K. Sexton: Spatial and termporal variability in outdoor, indoor, and personal $PM_{2.5}$ exposure. *Atmospheric Environment 36*: 3255–3265 (2002)

34. Hoek, G., B. Brunekreef, S. Goldbohm, P. Fischer, and P.A. van den Brandt: Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. *Lancet 360*: 1203–1209 (2002)

35. Brauer, M., G. Hoek, P. van Vliet, K. Meliefste, P. Fischer, U. Gehring, et al.: Estimating Long-Term Average Particulate Air Pollution Concentrations: Application of Traffic Indicators and Geographic Information Systems. *Epidemiology 14*: 228–239 (2003)

36. Saarela, K., T. Tirkkonen, J. Laine-Ylijoki, J. Juvelin, M.J. Nieuwenhuijsen, and M. Jantunen: Exposure of population and microenvironmental distributions of volatile organic compound concentrations in the EXPOLIS study. *Atmospheric Environment 37*: 5563–5575 (2003)

37. Brown, V.M., and D.R. Crump: Diffusive sampling of volatile organic compounds in ambient air. *Environmental Monitoring and Assessment 52*: 43–55 (1998)

38. Brown, R.H.: Monitoring the ambient environment with diffusive samplers: theory and practical considerations. *Journal of Environmental Monitoring 2*: 1–9 (2000)

39. Arnold, S.F.: Asymptotic Validity of *F*-Tests for the Ordinary Linear Model and the Multiple Correlation Model. *Journal of the American Statistical Association 75*: 890–895 (1980)

40. Morris, R.D., and E.N. Naumova: Carbon monoxide and hospital admissions for congestive heart failure: evidence of an increased effect at low temperatures. *Environ Health Perspect 106*: 649–653 (1998)

41. Yang, W., B.L. Jennison, and S.T. Omaye.: Cardiovascular disease hospitalization and ambient levels of carbon monoxide. *Journal of Toxicology and Environmental Health, Part A 55*: 185–196 (1998)

42. Atimtay, A.T., S. Emri, T. Bagci, and A.U. Demir: Urban CO Exposure and Its Health Effects on Traffic Policemen in Ankara. *Environmental Research Section A 82*: 222–230 (2000)

43. Zagury, E., Y.L. Moullec, and I. Momas: Exposure of Paris taxi drivers to automobile air pollutants within their vehicles. *Occupational and Environmental Medicine 57*: 406–410 (2000)

44. Ashmore, M.R., K. Batty, F. Machin, J. Gulliver, A. Grossinho, P. Elliott, et al.: Effects of traffic management and transport mode on the exposure of school children to carbon monoxide. *Environmental Monitoring and Assessment 65*: 49–57 (2000)

45. Venegas, L.E., and N.A. Mazzeo: Carbon monoxide concentration in a canyon of Buenos Aires City (Argentina). *Environmental Monitoring and Assessment 65*: 417–424 (2000)

46. Riediker M., R. Williams, R. Devlin, T. Griggs, and P. Bromberg: Exposure to Particulate Matter, Volatile Organic Compounds, and Other Air Pollutants Inside Patrol Cars. *Environ. Sci. Technol. 37*: 2084–2093 (2003)

47. Magari S.R., J. Schwartz, P.L. Williams, R. Hauser, T.J. Smith, and D.C. Christiani: The Association Between Personal Measurements of Environmental Exposure to Particulates and Heart Rate Variability. *Epidemiology 13*: 305–310 (2002)

48. Adams, H.S., M.J. Nieuwenhuijsen, R.N. Colvile, M.A.S. McMullen, and P. Khandelwal: Fine particle ($PM_{2.5}$) personal exposure levels in transport microenvironments, London, UK. *The Science of the Total Environment 279*: 29–44 (2001)

49. Pfeifer, G.D., R.M. Harrison, and D.R. Lynam: Personal exposures to airborne metals in London taxi drivers and office workers in 1995 and 1996. *The Science of the Total Environment 235*: 253–260 (1999)

50. Romieu, I., M. Ramirez, F. Maneses, D. Ashley, S. Lemire, S. Colome, et al.: Environmental Exposure to Volatile Organic Compounds among Workers in Mexico City as Assessed by Personal Monitors and Blood Concentrations. *Environ Health Perspect 107*: 511–515 (1999)

51. Jo, W.K., and K.B. Song: Exposure to volatile organic compounds for individuals with occupations associated with potential exposure to motor vehicle exhaust and/or gasoline vapor emissions. *The Science of the Total Environment 269*: 25–37 (2001)

52. Bono, R., E. Scursatone, T. Schilirò, and G. Gilli: Ambient air levels and occupational exposure to benzene, toluene, and xylenes in Northwestern Italy. *Journal of Toxicology and Environmental Health, Part A 66*: 519–531 (2003)

53. Jo, W.K., and C.H. Yu: Public Bus and Taxicab Drivers' Exposure to Aromatic Work-Time Volatile Organic Compounds. *Environmental Research Section A 86*: 66–72 (2001)

54. Bae, H., W. Yang, and M. Chung: Indoor and outdoor concentrations of RSP, NO_2 and selected volatile organic compounds at 32 shoe stalls located near busy roadways in Seoul, Korea. *Science of the Total Environment 323*: 99–105 (2004)

55. Mukherjee, A.K., S.K. Bhattacharya, S. Ahmed, S.K. Roy, A. Roychowdhury, and S. Sen: Exposure of drivers and conductors to noise, heat, dust and volatile organic compounds in the state transport special buses of Kolkata city. *Transportation Research Part D 8*: 11–19 (2003)

56. Edwards, R.D., J. Jurvelin, K. Saarela, and M. Jantunen: VOC concentrations measured in personal samples and residential indoor, outdoor and workplace microenvironments in EXPOLIS-Helsinki, Finland. *Atmospheric Environment 35*: 4531–4543 (2001)

57. Duffy, B.L., and P.F. Nelson: Exposure to emissions of 1,3-butadiene and benzene in the cabins of moving motor vehicles and buses in Sidney, Australia. *Atmospheric Environment 31*: 3877–3885 (1997)

CHAPTER 4

SUMMARY

Due to rapid industrialization and a lack of efficient control measures in many developing countries, urban traffic-related air pollution has been attracting increasing attention from environmental toxicologists and epidemiologists. A preliminary traffic-related personal exposure study was conducted among 58 workers (bus drivers, combi drivers, taxi drivers, street vendors, newspaper vendors, traffic police, and gas station attendants) and 10 office workers as controls, in Trujillo, Peru in July 2002. Airborne $PM_{2.5}$ was collected using a SKC pump with a flow rate of 4.0 L/min and BGI KTL Cyclone and Teflon-coated glass fiber filter with 2.0 μm pore size and 37 mm diameter. Carbon monoxide (CO) was measured by Pac III electrochemical sensors and Draeger stain tubes. Volatile organic compounds (VOCs) were sampled using Perkin-Elmer diffusion tubes and quantified by a gas chromatograph coupled with mass spectrometer (GC-MS). The CO exposure (Mean=11.4 ppm; SD=8.9 ppm) measured by stain tubes among the four newspaper vendors is higher than the WHO 8-hour standard of 8.7 ppm and USEPA 8-hour standard of 9 ppm. The $PM_{2.5}$ TWA (with an average sampling duration of 7.7 hrs) exposures among the groups in our study ranged from the lowest exposure among gas station attendants (Mean=64 $\mu g/m^3$; SD=26 $\mu g/m^3$) and office workers (Mean=65.2 $\mu g/m^3$; SD=8.5 $\mu g/m^3$) to the highest exposure among bus drivers (Mean=161 $\mu g/m^3$; SD=63 $\mu g/m^3$). VOC concentrations among different groups were quite different, with average benzene and toluene exposures ranging from 5.48 and 22 $\mu g/m^3$ for combi drivers to 139 and 500 $\mu g/m^3$ for bus drivers respectively. Another interesting finding was the higher exposures to all these pollutants among the smoking subjects. In addition, the smoking subjects were exposed to higher pollutants than nonsmokers as CO and BTEX (benzene, toluene, ethylbenzene, and xylene) are concerned, though small sample sizes may be blamed for the insignificance of the differences.

This preliminary study suggests that the traffic-related exposures investigated were of occupational health concern. A larger exposure assessment and health-effects investigation among these groups is warranted.

Table 1 1997 USEPA NAAQS standards

Pollutant (unit)	Time duration	Values
CO (ppm)	1 hour	35
	8 hour	9
NO2 (ppb)	Annual	53
PM10 ($\mu g/m^3$)	24 hour	150
	Annual	50
$PM_{2.5}$ ($\mu g/m^3$)	24 hour	65
	Annual	15
O3 (ppb)	1 hour	120
	8 hour	80
SO2 (ppb)	24 hour	140
	Annual	30
Lead ($\mu g/m^3$)	Quarter	1.5

Table 2 Regulatory values set by OSHA

Pollutants	Duration	Values
Benzene	8-hour work day or 40-hour work week	1ppm (3.19 mg/m^3)
Toluene	8-hour work day or 40-hour work week	200 ppm (753.6 mg/m^3)
Ethylbenzene	8-hour work day or 40-hour work week	100 ppm (434 mg/m^3)
Xylene	8-hour work day or 40-hour work week	100 ppm (434 mg/m^3)

Table 3 Guidelines of ambient air pollutants established by WHO in 2001

Polltants	Averageing Time	Values
CO	1 hour	30 mg/m^3(26 ppm)
	8 hours	10 mg/m^3(8.7 ppm)
Lead	1 year	0.5 $\mu g/m^3$(0.059 ppb)
NO2	1 hour	200 $\mu g/m^3$(106 ppb)
	1 year	40 $\mu g/m^3$(21 ppb)
O3	8 hours	120 $\mu g/m^3$(61 ppb)
SO2	24 hours	125 $\mu g/m^3$(47.7 ppb)
	1 year	50 $\mu g/m^3$(19.1 ppb)

Table 4 WHO guideline for BTEX in occupational settings (2001)

Pollutants	Averaging Time	Guidelines
Benzene	NA	$(4.4–7.5)\times10^{-6}$ $[\mu g/m^3]^{-1}$
Toluene	1 week	260 mg/m^3
Ethylbenzene	1 year	22000 mg/m^3
Xylene	24 hours	4800 mg/m^3
	1 year	870 mg/m^3
PAH (BaP)	NA	8.7×10^{-2} $[\mu g/m^3]^{-1}$

Table 5 Traffic-related exposure studies on airborne particulate matter

Study	Year	Location	Exposure Type (Sampling duration)	Size	Subject or place	Level ($\mu g/m^3$)
Leong et al., 2001	January–June 1999	Bangkok, Thailand	Ambient (24-hour)	PM_{10}	Busy street	84.33
Shendell, and Naeher, 2002	May and June 1997	Three cities, Guatemala	Ambient (248–370 min)	$PM_{2.5}$	Guatemala City Quetzaltenango	150[a] 120[a]
Wang et al., 2003	2001	Nanjing, China	Ambient (8:30 am–4:30 pm)	PM_{10} ($PM_{2.5}$)	Suyuan Hotel (high traffic)	632(423)
Chan et al., 2002	Summer 2000	Guangzhou, China	In-vehicle (Rush hours: 150 min)	PM_{10} ($PM_{2.5}$)	A/C Bus A/C Taxi Non-A/C Bus Non-A/C Taxi	128(101) 82(73) 203(145) 150(106)
Gómez-Perales et al., 2004	Spring 2002	Mexico City	In-vehicle (Rush hours: 180 min)	$PM_{2.5}$	Minibus Bus Metro	68 71 61
Kulkarni and Patil, 1999	1995–1996	Bombay, India	Personal (48 hours)	PM_5	Outdoor worker	322
Pfeifer et al., 1999	Summer 1996	London, UK	Personal exposure (7 days)	$PM_{2.5}$	Taxi driver	33.36
Adams et al., 2001	1999–2000	London, UK	In-vehicle (27 min)	$PM_{2.5}$	Bus (summer) Bus (winter) Car (summer) Car (winter)	39.0 38.9 37.7 33.7
Riediker et al, 2003	Fall 2001	Raleigh, NC, US	In-car (3pm–midnight) Roadside (same) Ambient (same)	$PM_{2.5}$ $PM_{2.5}$ $PM_{2.5}$	Patrol trooper Near traffic road Fixed site	23.0 31.7 29.9

[a] Value for the zone with the highest integrated average estimated over a workday of 8 hours.

Table 6 Traffic-related exposure studies on CO

Study	Year	Location	Exposure Type	Sampler (duration)	Subject or place	Level (ppm)
Venegas and Mazzeo, 2000	1994–1996	Buenos Aires, Argentina	Ambient	Non-dispersive infrared monitor (8 hours)	Downtown street canyon	10.2
Leong et al., 2001	January–June 1999	Bangkok, Thailand	Ambient	Non-dispersive infrared monitor (8 hours)	Busy street	6.15
Shendell and Naeher, 2002	May and June 1997	Three cities in Guatemala	Ambient	Langan Databear V (248–370 min)	Busy street	7.2[a] 10.9[b]
Atimtay et al., 2000	Spring 1998	Ankara, Turkey	Personal	Electrochemical sensor (8 hours)	Traffic policeman	6.26–23.89
Fernandez-Bremauntz and Ashmore, 1995	Winter 1991	Mexico City	In-vehicle	Electrochemical sensor (38–99 min)	Minibus Bus Metro	32–63 26–38 17–25
Chan et al., 2002	Summer 2000	Guangzhou, China	In-vehicle	Electrochemical sensor (2.5h peak)	Bus Taxi	8.6 23.7
Gómez-Perales et al., 2004	Spring 2002	Mexico City	In-vehicle	Electrochemcial sensor (180 min peak hours)	Minibus Bus Metro	15 12 7
Zagury et al., 2000	Spring 1997	Paris, France	Personal	Pac II sensor (8 hours)	Non-smoking taxi driver	3.8
Ashmore et al., 2000	Spring 1998	Northampton, UK	Personal	Pac III sensor (6–8 min in car traffic)	School children	4–7
Duci et al., 2003	Winter 1998–1999	Athens, Greece	In-vehicle	Electrochemical sensor (25–45 min)	Private car Bus trolley	21.4 10.4 9.6
Riediker et al, 2003	Fall 2001	Raleigh, NC, US	In-car Roadside Ambient	Electorchemical sensor (3pm–midnight)	Patrol trooper Near traffic Fixed site	2.6 1.1 0.8

[a] Value for the zones with the highest average over the whole monitoring period.
[b] Value for the zone with the highest Maximum average over 30-min

Table 7 Traffic-related exposure studies on O_3

Study	Location	Exposure Type (Sampling duration)	Subject or place	Level (ppb)
O'Neill et al., 2003	Mexico City	Personal (6.5 hours) and ambient	Shoe-cleaner Ambient	34.4 84
Bogo et al., 1999	Buenos Aires, Argentina	Ambient (continuous)	Fixed site	(monthly avergae)1–5
Leong et al., 2001	Bangkok, Thailand	Ambient (1 hour)	Busy street	6.8
Ha et al., 2003	Seoul, Korea	Ambient (NA)	Fixed site	(5-year TWA)21.2
Calderon-Garciduenas et al., 2003	Mexico City	Ambient (continuous)	Urban area	61–84(day) 12–20(night)
Sánchez-Carrillo et al, 2003	Mexico City	Ambient (Max 1-hour TWA)	Fixed site	102–140
Satsangi et al., 2004	Agra, India	Ambient (2-hour)	On a campus	(winter)28.5 (summer)22.1 (mosson)10.9
Wu, and Chan, 2001	Hong Kong	Ambient (monthly mean)	Rooftop station	(July)8–21 (October)30–52
McConnell et al., 2002	South California, US	Ambient (continuous)	Residential communities	(24-hour TWA)25–43
Riediker et al, 2003	Raleigh, NC, US	In-car, road, and ambient (3pm–midnight)	Patrol trooper Near traffic Fixed site	11.7 22.8 28.3

Table 8 Traffic-related exposure studies on SO_2

Study	Location	Exposure Type (Sampling duration)	Subject or place	Average Level (ppb)
Leong, et al., 2001	Bangkok, Thailand	Ambient (1 hour)	Urban traffic street	3.66
Gouveia, and Fletcher, 2000	São Paulo, Brazil	Ambient (24-hour)	13 monitoring stations	6.99
Lin et al., 2004	São Paulo, Brazil	Ambient (24-hour)	Fixed stations	5.85
Lee et al., 2000	Korea	Ambient (continuous)	Several cities	23.3
Reddy and Ruj, 2003	West Bengal, India.	Ambient (24-hour)	Fixed sites in Raniganj-Asansol	3.58–4.17(summer) 4.18–4.76(monsoon) 6.70–7.21(winter)
Ta et al., 2004	Lanzhou, China	Ambient (continous)	Fixed sites	35.9–79.4(winter) 8.4–27.5(spring) 1.5–13.0(summer) 9.5–36.3(fall)
Delfino et al., 2003	Los Angeles County, California	Ambient (1-hour sampling for months)	Huntington Park region	7.0(1-hour max) 4.6(8-hour max)

Table 9 Traffic-related exposure studies on lead

Study	Location	Exposure Type (Sampling duration)	Subject or place	Averaging period	Level ($\mu g/m^3$)
Schirnding and Fuggle, 1996)	Cape Town, South Africa	Ambient (24-hour)	Highest traffic site	Annual	2.1
Tripathi et al., 2001	Mumbai, India	Ambient (24-hour)	Multi-sites	1984–1996 average	(highest)41.2 (second highest)6.7 (others)0.1–1.2
Jain et al., 2002	Dhanbad, India	Ambient (24-hour)	Dhanbad-Jharia Road	Monsoon Winter	1.5–3.1 1.8–3.3
Smichowski et al., 2004	Buenos Aires, Argentina	Ambient (8-day)	Fixed sites	Winter	0.025
Zheng et al., 2004	Shanghai, China	Ambient (21–49 days)	Multi-sites	Winter	0.515

Table 10 Traffic-related exposure studies on VOCs

Study	Location	Exposure Type (duration)	Subject or place	Pollutants	Level (μg/m^3)
Wang et al., 2002	China	urban roadside (30min)	Guangzhou	BTEX	51.5/77.3/17.8/81.6
			Macau	BTEX	34.9/85.9/24.1/95.6
			Nanhai	BTEX	20.0/39.1/3.0/14.2
Bae et al., 2004	Seoul, Korea	Indoor (8 hours)	Shoe stall salesperson	BTX	732/6777/5382
Mukherjee et al., 2003	Kolkata, Inida	Personal (3–4 hours)	Bus driver	Benzene	527.3
				Toluene	472.8
				o-xlyene	1265.5
				p-xylene	402.8
Jo and Yu, 2001	Taegu, Korea	Personal (7–8 hours)	ETS bus driver	BTEX	28.1/88.7/8.1/30.2
			Non-ETS bus driver	BTEX	14.5/49.5/7.0/21.4
			ETS taxi driver	BTEX	44/141/10.2/37.3
			ETS taxi driver	BTEX	24.8/80.8/8.8/23.6
Jo and Song, 2001	Taegu, Korea	Personal (6–11 hours)	Traffic policeman		
			Smoker	BTEX	35.3/114/7.8/22.1
			Non-smoker	BTEX	24.2/125/7.7/27.2
			Gas station attendant		
			Smoker	BTEX	84.4/141/12.9/55.1
			Non-smoker	BTEX	72.1/126/12.1/50.7
Romieu, 1999	Mexico City	Personal (workshift)	Gas station attendant	BTEX	310/680/110/490
			Street vendor	BTEX	77/160/28/128
			Office worker	BTEX	44/470/17/81
Bravo et al., 2002	Mexico City	Ambient (2–24 hours)	Gas station	Benzene	82.4
				Toluene	319.8
Barletta et al., 2002	Karachi, Pakistan	Ambient (4–6 hours)	Traffic street	BTX	16.6/26.8/8.2
Lau and Chan, 2003	Hong Kong, China	In-vehicle (30–50 min)	Non-A/C bus	BTEX	4.8/54.3/3.1/6.2
			A/C bus	BTEX	6.1/72.9/6.9/15.5
			Taxi	BTEX	5.9/43.5/4.4/7.8
Gómez-Perales et al., 2004	Mexico City	In-vehicle (3 hours)	Minibus	Benzene	22
			Bus	Benzene	19
			Metro	Benzene	13
Chan et al., 2003	Guangzhou, China	In-vehicle (2.5 hours)	Bus	BTEX	12.4/56.4/8.3/17.5
			Taxi	BTEX	33.6/108.5/20.3/43.2
Bono et al., 2003	Biella and Torino, Italy	Personal (8 hours)	Gas pump attendant	Summer BTX	503/712/379*
				Winter BTX	161/568/285*
			Policeman	Summer BTX	31/215/73*
				Winter BTX	21/144/150*
Edwards et al., 2001	Helsinki, Finland	Personal (48 hours)	Non-ETS group	BTEX	2.6/17.1/3.3/15.1
			ETS exposed group	BTEX	4.7/73.6/14.6/66.5
Gonzalez-Flesca, et al, 2000	Rouen, France	Personal (5 days)	Non-smoker	Benzene	10.3
Duffy and Nelson, 1997	Sidney, Australia	In-vehicle (45–60 min)	Non-catalyst-equipped	Benzene	153.7
			Catalyst-equipped	Benzene	70.6
Batterman et al., 2002	Detroit, USA	Vehicle/roadway (2–3 hours)	Bus	BTEX	4.5/10.2/9/2.1
Riediker et al, 2003	Raleigh, NC, US	In-car, road, and ambient (3pm–midnight)	Patrol trooper	BTEX	4/10.4/0.9/4.5
			Near traffic	BTEX	0.2/1.5/0.2/1
			Fixed site	BTEX	0.1/1.7/0.2/1

Table 11 Traffic-related exposure studies on NOx

Study	Location	Exposure Type (Sampling duration)	Subject/Location	Pollutant	Level (ppb)
Son et al., 2004	Asan and Seoul, Korea	Personal and microenvironments (varies)	Taxi drivers	NO_2	30.3
			In-vehicle	NO_2	27.4
			Indoor home	NO_2	24.7
			Outdoor home	NO_2	23.3
Mondal et al., 2000	Calcutta, India	Ambient (14-day passive sampling)	Intersection (Winter)	NOx	222
			Intersection (Summer)		55
Leong et al., 2001	Bangkok, Thaiand	Ambient (1 hour)	Busy street	NO_2	30.2
Fagundez, et al., 2001	Buenos Aires, Argentina	Ambient (18–26 days)	Street level	NO_2	5–36
Lin et al., 2004	São Paulo, Brazil	Ambient (24-hour)	Fixed stations	NO_2	50.3
Bae et al., 2004	Seoul, Korea	Indoor and traffic (8 hours)	Shoe stalls	NO_2	57.4
			Busy street	NO_2	58.1
Ta et al., 2004	Lanzhou, China	Ambient (continuous)	Fixed sites(winter)	NO_2	36–47
			Fixed sites(spring)	NO_2	19–28
			Fixed sites(summer)	NO_2	14–28
			Fixed sites(fall)	NO_2	27–40
Riediker et al, 2003	Raleigh, NC, US	In-car, roadside, and ambient (3pm–midnight)	Patrol trooper	NO_2	41.7
			Near traffic	NO_2	49.9
			Fixed site	NO_2	30.4
Singer et al., 2004	Northern California, US	Ambient (1-wk passive sampling)	Schools (downwind) near a highway	NO_2	24–30

Table 12 Traffic-related exposure studies on PAHs

Study	Location	Exposure Type (Sampling duration)	Subject or place	Pollutant	Time	Level (ng/m^3)
Ruchirawat et al, 2002	Bangkok, Thailand	Personal (3-hour)	Traffic police	PAHs	Dry season	72.79
			Office police	PAHs	Dry season	6.88
Kuo et al., 2003	Taichung, Taiwan	Personal (6-hours)	Incense smoke	PAHs	Not available	147
		Personal (1-hour)	In-vehicle	PAHs		929
Szaniszló J., and Ungváry G, 2001	Budapest, Hungary	Personal (work shift)	Traffic police	PAHs	Jan.	60.7
			Road builders	PAHs	Jan.	79.2
			Traffic police	BaP	Jan.	8.2
			Road builders	BaP	Jan.	0.6
Qi et al., 2002	Macao, China	Ambient	Four traffic sites	13 PAHs	Winter night	13–51
					Winter day	16–80
de P. Pereira, et al., 2002	Salvador, Brazil	Ambient (2–3 hours)	Bus station	BaP	Apr.	3.06
			Traffic tunnel	BaP	Aug.	12.60
Chetwittayachan et al., 2002	Bangkok	Ambient (7-day)	Roadside	PAHs	Mar.	52
	Tokyo		Roadside	PAHs	Aug.	29
Šišovic et al., 2002	Zagreb, Croatia	Ambient (24-hour)	One fixed site	BaP	Summer	0.05
				BaP	Winter	5.12
Barakat, 2002	Alexandria City, Egypt	Ambient (30-day)	Roadside	pPAHs	Jul.–Aug.	32
Marr et al., 2004	Mexico City	Ambient (≥1 hour)	Roadside	pPAHs	Winter and summer	60–910
Levy et al., 2001	Roxbury, Massachusetts	Fixed (7–11am)	Bus terminal	PAHs	Summer	16
		Personal (7–11am)	Bus terminal	PAHs	Summer	29
Lodovici et al., 2003	Florence, Italy	Ambient (24-hour)	Traffic site	BaP	Winter	2.1

Table I. CO TWA (ppm) measured by Pac III real-time chemical sensor and Stain Tube

Method (Duration)	Occupation	Mean	SD	N	95% CI	Min	Max
Chemical sensor (Max 15-sec TWA)	Gas Station Attendant	64.900	40.769	10	35.74–94.06	15.00	123.00
	Traffic Police	32.600	17.344	5	11.07–54.13	17.00	56.00
	Combi Driver	18.140	7.128	7	11.55–24.74	9.00	29.00
	Taxi Driver	18.000	7.810	5	8.30–27.70	10.00	29.00
	Bus Driver	11.630	6.968	8	5.80–17.45	5.00	27.00
	Office Worker	7.100	4.280	10	4.04–10.16	0	15.00
	Total	26.510	29.592	45	17.62–35.40	0	123.00
Chemical sensor (Max 15-min TWA)	Gas Station Attendant	7.503	6.876	10	2.584–12.422	0.77	24.29
	Traffic Police	7.268	3.286	5	3.188–11.348	2.77	11.55
	Taxi Driver	5.600	3.841	5	0.831–10.369	1.29	11.06
	Combi Driver	5.010	3.040	7	2.198–7.822	1.90	9.90
	Bus Driver	2.440	2.029	8	0.744–4.136	0.74	6.23
	Office Worker	1.699	1.118	10	0.899–2.499	0	3.42
	Total	4.688	4.448	45	3.352–6.024	0	24.29
Chemical sensor (Max 1-hour TWA)	Traffic Police	4.804	2.854	5	1.261–8.347	1.20	8.20
	Gas Station Attendant	4.049	3.362	10	1.644–6.4543	0.24	9.67
	Taxi Driver	3.154	2.242	5	0.370–5.938	0.66	6.33
	Combi Driver	1.837	1.028	7	0.886–2.788	0.88	3.23
	Bus Driver	1.016	1.159	8	0.047–1.986	0.28	3.73
	Office Worker	0.573	0.444	10	0.255–0.891	0	1.45
	Total	2.378	2.531	45	1.618–3.138	0	9.67
Chemical sensor (Full shift TWA)	Traffic Police	2.818	1.617	5	0.811–4.825	0.67	4.22
	Gas Station Attendant	2.267	2.122	10	0.749–3.785	0.05	6.39
	Taxi Driver	0.868	0.543	5	0.194–1.542	0.18	1.52
	Combi Driver	0.463	0.304	7	0.182–0.744	0.13	0.89
	Bus Driver	0.235	0.311	8	-0.025–0.495	0.05	0.99
	Office Worker	0.095	0.089	10	0.031–0.159	0	0.29
	Total	1.048	1.514	45	.593–1.503	0	6.39
Stain Tube (full shift TWA)	Newspaper Vendor	11.440	8.931	4	-2.771–25.651	6.18	24.79
	Gas Station Attendant	4.778	1.963	18	3.802–5.754	1.25	9.38
	Traffic Police	3.758	1.864	6	1.802–5.714	2.05	6.58
	Taxi Driver	3.103	0.744	10	2.571–3.635	1.98	4.19
	Street Vendor	2.918	2.591	4	-1.205–7.042	0.68	6.65
	Combi Driver	2.902	0.847	8	2.194–3.611	1.51	4.23
	Bus Driver	2.363	0.693	8	1.783–2.942	1.099	3.22
	Office Worker	2.048	1.747	10	0.798–3.298	0	4.90
	Total	3.818	3.222	68	3.038–4.598	0	24.79

Table II. $PM_{2.5}$ exposures among the groups ($\mu g/m^3$)

Occupation	Mean	SD	N	95% CI	Min	Max
Bus Driver	160.960	63.430	3	3.390–318.529	100.121	226.698
Combi Driver	114.455	26.887	5	81.071–147.839	90.598	157.541
Traffic Police	89.537	29.411	4	42.737–136.336	65.081	131.069
Office Worker	65.210	8.494	5	54.663–75.756	55.412	77.775
Gas Station Attendant	64.006	26.493	10	45.055–82.958	21.498	110.619
Total	88.126	42.954	27	71.134–105.118	21.498	226.698

Table III. BTEX exposures among the groups ($\mu g/m^3$)

Pollutant	Occupation	Mean	SD	N	95% CI	Min	Max
Benzene	Traffic Police	187.504	NA	1	NA	187.504	187.504
	Bus Driver	138.554	112.938	4	-41.156–318.264	17.547	243.665
	Gas Station Attendant	110.617	118.396	16	47.529–173.705	1.160	470.336
	Taxi Driver	8.354	3.487	9	5.674–11.034	1.553	12.749
	Combi Driver	5.483	1.745	4	2.707–8.260	3.536	7.167
	Total	76.727	104.003	34	40.439–113.015	1.160	470.336
Toluene	Traffic Police	668.061	NA	1	NA	668.061	668.061
	Bus Driver	499.564	440.686	5	-47.619–1046.745	120.864	1091.460
	Gas Station Attendant	253.853	225.966	15	128.717–378.989	51.745	927.338
	Taxi Driver	37.327	16.556	9	24.601–50.053	12.743	75.650
	Combi Driver	22.267	7.377	4	10.530–34.005	15.457	31.379
	Office Worker	10.172	NA	1	NA	10.172	10.172
	Total	211.682	276.590	35	116.670–306.694	10.172	1091.460
Ethylbenzene	Gas Station Attendant	43.169	40.116	12	17.681–68.657	15.004	154.236
	Taxi Driver	4.626	1.633	9	3.371–5.881	2.404	7.091
	Combi Driver	2.611	1.419	4	0.363–4.864	0.580	3.704
	Total	22.804	33.734	25	8.880–36.729	0.580	154.236
Xylene	Gas Station Attendant	213.587	197.353	12	88.194–338.979	90.949	769.084
	Taxi Driver	27.619	10.198	9	19.780–35.457	14.155	43.599
	Combi Driver	15.630	5.552	4	6.795–24.465	8.578	21.282
	Total	114.965	165.102	25	46.815–183.116	8.578	769.084

Table IV. m-xylene, o-xylene, and p-xylene exposures (µg/m³)

Pollutant	Occupation	Mean	SD	N	Min	Max
m-xylene	Combi Driver	8.133	2.008	4	5.462	10.319
	Taxi Driver	13.736	4.253	9	7.774	21.028
	Gas Station Attendant	110.148	110.473	12	36.878	416.917
	Total	59.118	90.043	25	5.462	416.917
o-xylene	Combi Driver	3.556	0.940	4	2.213	4.400
	Taxi Driver	6.427	1.956	9	4.050	10.046
	Gas Station Attendant	51.220	57.317	12	1.050	211.392
	Total	27.468	45.283	25	1.050	211.392
p-xlyene	Combi Driver	3.940	3.475	4	0.903	8.834
	Taxi Driver	7.455	5.766	9	2.330	17.464
	Gas Station Attendant	52.219	33.756	12	20.213	140.775
	Total	28.379	32.905	25	0.903	140.775

Table V-A Descriptive Statistics for Other VOCs (µg/m³)

Occupation		1,2,3-TMB[a]	1,2,4-TMB[a]	1,3,5-TMB[a]	Acetone	Acetonitrile	α-pinene	Benzaldehyde	Butal
Combi Driver	Mean	2.9094	4.7108	1.0527	111.9871	1.4058	0.5730	30.2254	11.2339
	Median	2.8503	5.0522	1.1093	42.6972	1.3609	0.5800	23.6847	11.4970
	N	4	4	4	4	4	4	4	4
	SD	0.3901	1.1167	0.3585	153.0659	0.9210	0.0411	16.1140	1.5666
	Min	2.5050	3.0903	0.6100	21.5940	0.5600	0.5000	19.6387	9.0957
	Max	3.4320	5.6485	1.3800	340.9600	2.3412	0.6000	53.8933	12.8462
Taxi Driver	Mean	4.0239	8.6408	2.3134	38.3117	1.4866	0.5910	33.3853	10.9925
	Median	3.6340	9.2477	2.3148	33.6889	1.8194	0.5900	31.3631	11.3636
	N	9	9	9	9	9	9	9	9
	SD	0.9775	2.2242	0.5060	10.9341	0.9180	0.0252	11.2285	1.5030
	Min	2.9398	5.7180	1.4100	26.5827	0.5300	0.6000	20.2674	8.3587
	Max	5.7264	12.2179	3.0200	57.3820	2.7267	0.6000	54.2993	13.8253
Gas Station Attendant	Mean	15.0554	48.0315		298.9997	4.0534	1.5070	60.5846	36.8368
	Median	11.0811	27.9028	9.3502	247.7160	1.3359	1.1000	53.5634	37.2014
	N	12	12	12	12	12	12	12	12
	SD	12.1948	53.8720	18.3052	186.0041	4.7650	1.0822	31.0293	13.0000
	Min	3.6075	13.8688	3.6600	76.4734	0.9400	0.9000	2.8860	16.7951
	Max	46.9987	200.5534	56.4900	826.0213	14.9794	4.7000	107.8189	55.2349
Total	Mean	9.1407	26.9195	9.5158	175.2300	2.7057	1.0280	45.9354	23.4364
	Median	5.3423	12.2179	3.0185	76.4734	1.4517	0.6400	40.0973	13.8253
	N	25	25	25	25	25	25	25	25
	SD	10.1133	41.9801	14.7946	184.8831	3.5413	0.8707	26.8937	15.8489
	Min	2.5050	3.0903	.6100	21.5940	0.5300	0.5000	2.8860	8.3587
	Max	46.9987	200.5534	56.4900	826.0213	14.9794	4.7000	107.8189	55.2349

[a] TMB: trimethylbenzene

Table V-B Descriptive Statistics for Other VOCs (µg/m^3) (Continued)

Occupation		Butylbenzene	Decane	Dodecane	Heptane	Hexane	Isoprene	Isopropanol	Limonene
Combi Driver	Mean	0.5825	3.4499	15.4801	4.0221	3.4310	3.3293	1.5020	19.4786
	Median	0.5900	3.0103	15.1646	3.8279	2.9154	3.3341	1.4518	16.8831
	N	4	4	4	4	4	4	4	4
	SD	0.0411	1.4727	2.7270	1.8543	2.8714	1.3453	0.8482	7.4555
	Min	0.5300	2.2030	12.7391	2.1070	0.9815	2.0497	0.5200	13.9601
	Max	0.6200	5.5759	18.8522	6.3255	6.9117	4.5991	2.5845	30.1880
Taxi Driver	Mean	0.9693	4.7196	16.6073	6.7997	9.3287	4.9178	8.5072	33.7224
	Median	1.2043	4.9830	15.1678	6.3131	7.9401	4.3519	2.0363	13.0652
	N	9	9	9	9	9	9	9	9
	SD	0.3538	2.0813	3.1562	2.7895	6.4916	1.7241	10.9575	41.9813
	Min	0.5700	2.5637	14.1667	1.6204	1.3657	3.2837	0.5100	7.4163
	Max	1.3600	8.9822	24.2911	9.7983	19.3091	8.7442	27.4306	135.5408
Gas Station Attendant	Mean	3.6662	15.8987	37.4184	150.2298	511.1020	17.1816	187.8281	19.6173
	Median	2.7137	13.6050	31.7243	97.2538	382.3512	13.2003	73.8005	14.8560
	N	12	12	12	12	12	12	12	12
	SD	2.0911	11.6161	15.2281	125.5315	356.0514	10.6981	201.0387	15.0552
	Min	1.8200	3.6095	24.5711	41.6122	108.8261	7.1641	0.9400	1.0000
	Max	8.3400	40.9962	71.6897	454.9596	1280.2469	41.8476	557.6217	53.0283
Total	Mean	2.2019	9.8824	26.4163	75.2017	249.2362	10.5502	93.4604	24.6729
	Median	1.3623	5.5759	24.2911	9.7983	19.3091	7.1641	19.9500	14.8663
	N	25	25	25	25	25	25	25	25
	SD	2.0310	9.9272	15.0689	112.4238	352.2207	9.8106	164.7203	27.3184
	Min	0.5300	2.2030	12.7391	1.6204	0.9815	2.0497	0.5100	1.0000
	Max	8.3400	40.9962	71.6897	454.9596	1280.2469	41.8476	557.6217	135.5408

Table V-C Descriptive Statistics for Other VOCs (μg/m^3) (Continued)

Occupation		MEK[a]	MCB[b]	MCP[c]	Nonane	Propyl-benzene	Styrene	Tridecane	Undecane
Combi Driver	Mean	2.7382	5.3251	1.6199	4.6494	0.5700	3.7051	45.4173	11.1006
	Median	2.8283	5.1631	1.3545	4.1082	0.5650	3.4806	43.9746	10.4774
	N	4	4	4	4	4	4	4	4
	SD	1.7522	2.0753	1.4598	2.4062	0.0374	0.9772	8.9346	2.6295
	Min	0.5671	3.3713	0.3926	2.6829	0.5300	2.8328	36.9963	8.7903
	Max	4.7291	7.6028	3.3781	7.6982	0.6200	5.0265	56.7234	14.6575
Taxi Driver	Mean	3.3347	11.7651	5.4418	9.0018	0.6033	3.5803	42.1853	11.4007
	Median	3.8113	10.0800	4.2019	10.0569	0.6000	3.5295	43.6871	10.9011
	N	9	9	9	9	9	9	9	9
	SD	2.0360	5.6162	3.5314	3.2672	0.0245	0.4494	9.1844	2.2372
	Min	0.5600	4.3519	1.1806	4.2130	0.5700	3.0220	21.2100	8.7500
	Max	5.9648	22.7997	12.7929	13.0177	0.6500	4.2314	55.9538	15.6553
Gas Station Attendant	Mean	7.6378	177.5489	354.2073	34.7124	3.8714	5.6270	96.0370	27.1587
	Median	3.5476	120.7993	231.5801	32.8917	1.1900	5.4513	86.4278	24.3087
	N	12	12	12	12	12	12	12	12
	SD	10.5123	151.1966	322.8869	16.7726	6.1327	2.4641	34.9784	9.7725
	Min	0.5600	25.3327	40.4815	9.3246	0.8800	1.1000	67.2192	16.7949
	Max	37.4292	546.0622	1033.9293	74.0400	22.3100	10.1733	180.4938	48.4820
Total	Mean	5.3048	90.3109	172.2378	20.6465	2.1667	4.5827	68.5512	18.9166
	Median	3.4568	22.7997	12.7929	12.6922	0.6500	4.1854	56.7234	15.6553
	N	25	25	25	25	25	25	25	25
	SD	7.5954	133.4589	282.1869	18.0457	4.4758	2.0050	36.4208	10.5658
	Min	0.5600	3.3713	0.3926	2.6829	0.5300	1.1000	21.2100	8.7500
	Max	37.4292	546.0622	1033.9293	74.0400	22.3100	10.1733	180.4938	48.4820

[a] MEK: Methyl ethyl ketone; [b] MCB: Methylcyclohexane; [c] MCP: Methylcyclopentane

Table VI Smoking and exposures to the CO, $PM_{2.5}$, and BTEX[Mean(sample size)]

Smoking	CO-Tube (ppm)	Max 1-hour CO (ppm)	Full shift CO (ppm)	$PM_{2.5}$ (μg/m^3)	Benzene (μg/m^3)	Toluene (μg/m^3)	Ethylbenzene (μg/m^3)	Xylene (μg/m^3)
Yes	4.1(11)	3.6(8)	2.1(8)	77.0(2)	151.2(5)	311.2(5)	58.8(3)	299.2(3)
No	3.7(45)	1.9(30)	0.7(30)	90.9(19)	48.6(20)	164.0(19)	11.4(15)	53.0(15)
t-test p-value	0.298	0.085	0.075	0.692	0.070	0.147	0.091	0.054
Mann-Whitney test p-value	0.359	0.183	0.070	0.610	0.071	0.088	0.164	0.203

Table VII. CO exposures in different exposure assessment studies

Study	Year	Location	Exposure Type (duration)	Sampler	Subject or vehicle	Level (ppm)
Our Study	Winter (July) 2002	Trujillo, Peru	Personal (about 8 hours)	Stain tube	Bus driver	2.36
					Taxi driver	3.10
				Pac III sensor	Bus driver	0.24
					Taxi driver	0.87
					Traffic policeman	2.82
Venegas, et al, 2000[45]	1994–1996	Buenos Aires, Argentina	Ambient (8 hours)	Non-dispersive infrared monitor	N/A	10.2
Duci, et al, 2003[18]	Winter 1998–1999	Athens, Greece	In-vehicle (2h peak)	Electrochemical sensor	Private car	21.4
					Bus	10.4
					trolley	9.6
Chan, et al, 2002[12]	Summer 2000	Guangzhou, China	In-vehicle (2.5h peak)	Electrochemical sensor	Bus	8.6
					Taxi	23.7
Gómez-Perales, et al, 2004[13]	Spring 2002	Mexico City	In-vehicle (3h peak hours)	Electrochemcial sensor	Minibus	15
					Bus	12
					Metro	7
Riediker et al, 2003[46]	Fall 2001	Raleigh, NC, US	In-car, Roadside, Ambient (3pm–midnight)	Electorchemical sensor	Patrol trooper	2.6
					Near traffic	1.1
					Fixed site	0.8
Ashmore, et al, 2000[44]	Spring 1998	Northampton, UK	Personal (6–8 min in car traffic)	Pac III sensor	School children	4–7
Atimtay, et al, 2000[42]	Spring 1998	Ankara, Turkey	Personal (8 hours)	Electrochemical sensor	Traffic policeman	6.26–23.89
Zagury, et al, 2000[43]	Spring 1997	Paris, France	Personal (8 hours)	Pac II sensor	Non-smoking taxi driver	3.8

Table VIII. $PM_{2.5}$ exposures in different exposure assessment studies

Study	Year	Location	Exposure Type (duration)	Sampler	Subject or vehicle	Level ($\mu g/m^3$)
Our Study	Winter (July) 2002	Trujillo, Peru	Personal (8 hours)	BGI KTL cyclone	Bus driver	161
					Combi driver	114
Adams et al, 2001[48]	1999–2000	London, UK	In-vehicle (27 min)	High flow gravimetric sampler	Bus in summer	39.0
					Bus in winter	38.9
					Car in summer	37.7
					Car in winter	33.7
Chan et al, 2002[12]	Summer 2000	Guangzhou, China	In-vehicle (2.5h peak)	DustTrak light-scattering sampler	A/C Bus	101
					A/C Taxi	73
					Non-A/C Bus	145
					Non-A/C Taxi	106
Gómez-Perales et al, 2004[13]	Spring 2002	Mexico City	In-vehicle (180 min rush hours)	High flow portable sampler	Minibus	68
					Bus	71
					Metro	61
Riediker et al, 2003[46]	Fall 2001	Raleigh, NC, US	In-car	$PM_{2.5}$	Patrol trooper	23.0
			Roadside	$PM_{2.5}$	Near traffic road	31.7
			Ambient (3pm–midnight)	$PM_{2.5}$	Fixed site	29.9
Pfeifer et al, 1999[49]	Summer 1996	London, UK	Personal exposure (7 days)	Harvard-Marple Impactor	Taxi driver	33.36

Table IX. VOC exposures in different exposure assessment studies

Study	Location	Exposure Type	Subject or vehicle	Pollutant	Level (μg/m^3)
Our Study	Trujillo, Peru	Personal (8 hours)	Combi driver	BTEX	5.5/22.3/2.6/15.6
			Taxi driver	BTEX	8.4/37.3/4.6/27.6
			Gas station attendant	BTEX	111/254/43/214
Mukherjee et al, 2003[55]	Kolkata, Inida	Personal (3–4h)	Bus driver	Benzene	527.3
				Toluene	472.8
				o-xlyene	1265.5
				p-xylene	402.8
Jo et al, 2001a[53]	Taegu, Korea	Personal (7–8 hours)	ETS bus driver	BTEX	28.1/88.7/8.1/30.2
			Non-ETS bus driver	BTEX	14.5/49.5/7.0/21.4
			ETS taxi driver	BTEX	44/141/10.2/37.3
			Non-ETS taxi driver	BTEX	24.8/80.8/8.8/23.6
Bono et al, 2003[52]	Biella and Torino, Italy	Personal (8 hours)	Petrol pump attendant	Summer BTX	503/712/379*
				Winter BTX	161/568/285*
			Policeman	Summer BTX	31/215/73*
				Winter BTX	21/144/150*
Romieu, 1999[50]	Mexico City	Personal (work shift)	Service station attendants	BTEX	310/680/110/490
			Street vendor	BTEX	77/160/28/128
			Office worker	BTEX	44/470/17/81
Jo et al, 2001b[51]	Taegu, Korea	Personal (6–11 hours)	Traffic policeman		
			Smoker	BTEX	35.3/114/7.8/22.1
			Non-smoker	BTEX	24.2/125/7.7/27.2
			Gas station attendant		
			Smoker	BTEX	84.4/141/12.9/55.1
			Non-smoker	BTEX	72.1/126/12.1/50.7
Edwards et al, 2001[56]	Helsinki, Finland	Personal (48 hours)	Non-ETS exposed	BTEX	2.6/17.1/3.3/15.1
			ETS exposed	BTEX	4.7/73.6/14.6/66.5
Gonzalez-Flesca et al, 2000[20]	Rouen, France	Personal (5 days)	Non-smoker	Benzene	10.3
Lau et al, 2003[23]	Hong Kong, China	In-vehicle (30–50min)	Non-A/C bus	BTEX	4.8/54.3/3.1/6.2
			A/C bus	BTEX	6.1/72.9/6.9/15.5
			Taxi	BTEX	5.9/43.5/4.4/7.8
Duffy et al, 1997[57]	Sidney, Australia	In-vehicle (45–60min)	Non-catalyst-equipped	Benzene	153.7
			Catalyst-equipped	Benzene	70.6
Chan et al, 2002[12]	Guangzhou, China	In-vehicle (2.5h peak)	Bus	BTEX	12.4/56.4/8.3/17.5
			Taxi	BTEX	33.6/108.5/20.3/43.2
Batterman et al, 2002[21]	Detroit, US	In-vehicle and roadway (2–3 h)	Bus	BTEX	4.5/10.2/9/2.1
Gómez-Perales et al, 2004[13]	Mexico City	In-vehicle (3 h)	Minibus	Benzene	22
			Bus	Benzene	19
			Metro	Benzene	13
Riediker et al, 2003[46]	Raleigh, NC, US	In-car, road, and ambient (3pm–midnight)	Patrol trooper	BTEX	4/10.4/0.9/4.5
			Near traffic	BTEX	0.2/1.5/0.2/1
			Fixed site	BTEX	0.1/1.7/0.2/1
Bae et al, 2004[54]	Seoul, Korea	Indoor (near road) (8 hours)	Shoe stall salesperson	BTX	732/6777/5382

* Geometric means

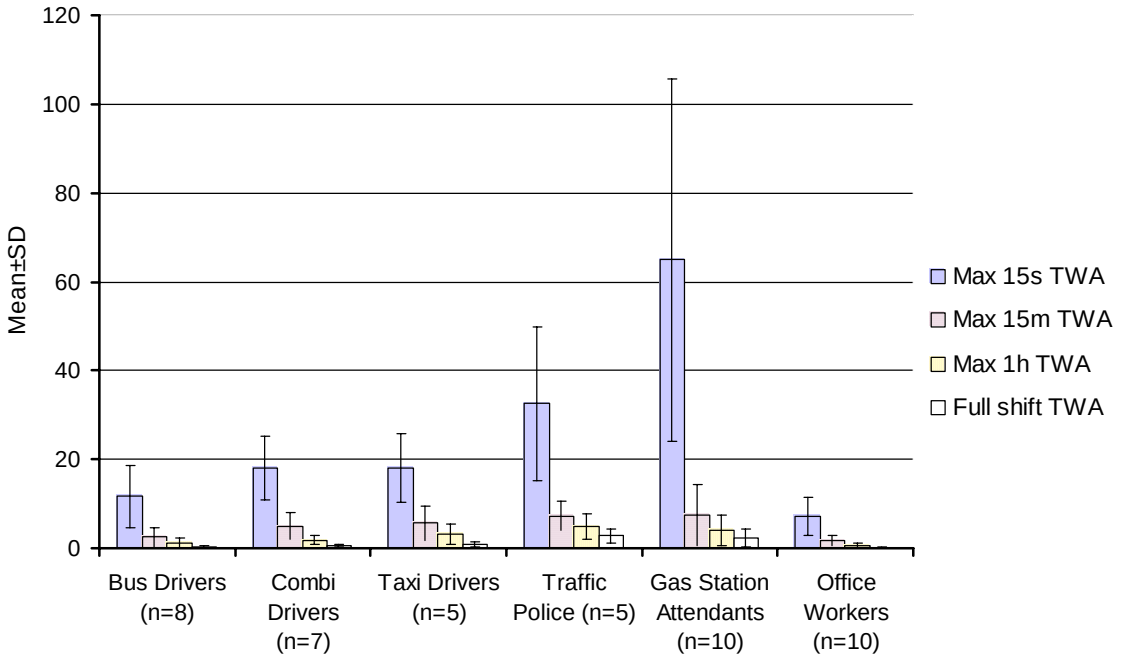

Figure 1 Occupational Exposures (ppm) to carbon monoxide measured by Daeger Pac III Chemical Sensors

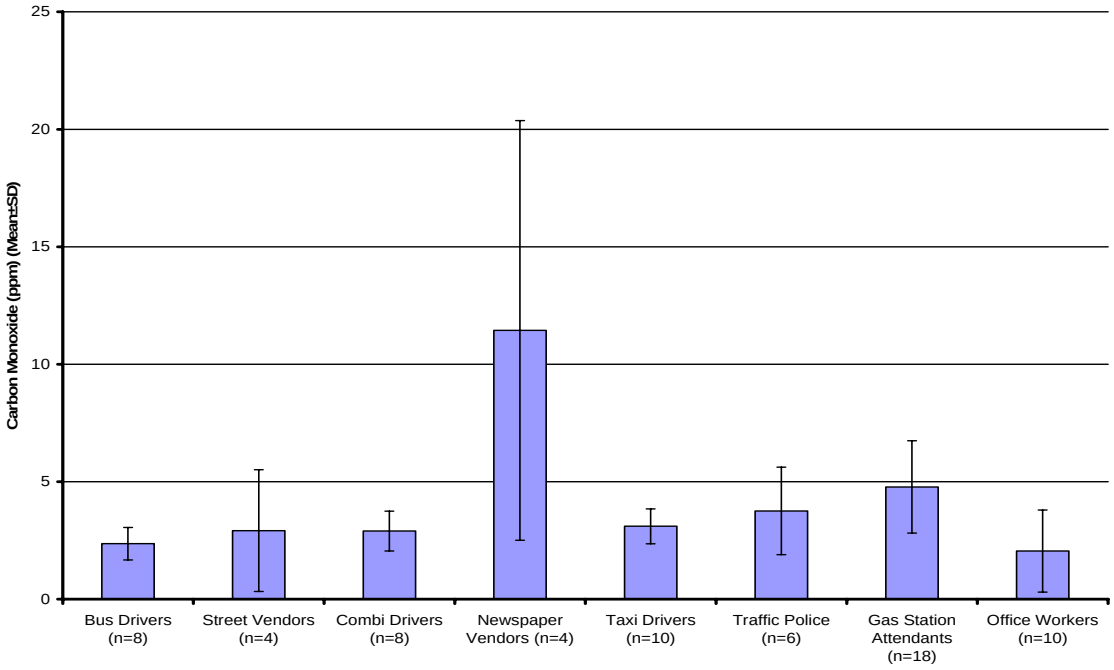

Figure 2 Occupational Exposures to Carbon Monoxide Using Draeger Diffusion Stain Tubes

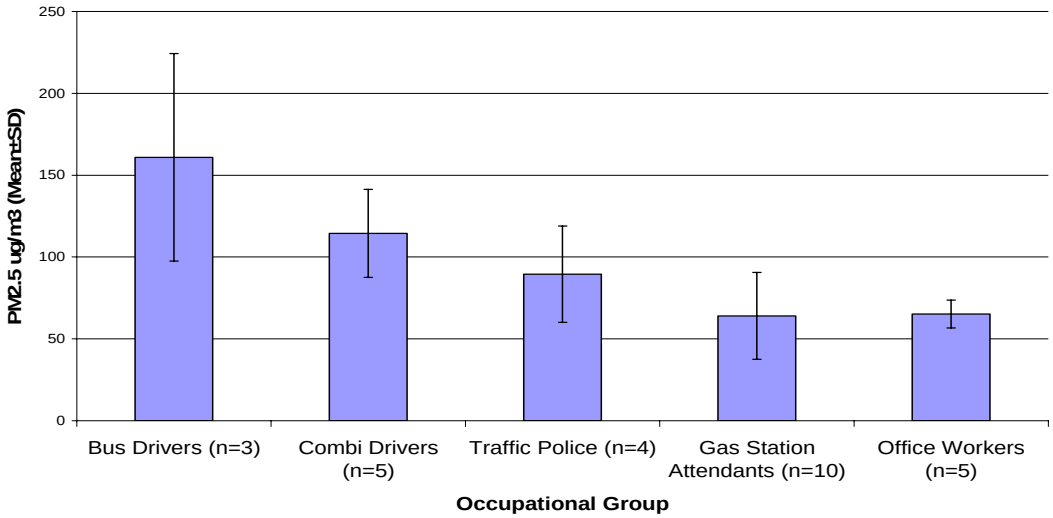

Figure 3 Occupational Exposures to $PM_{2.5}$ Measured by SKC Pumps at 4.0 L/min, BGI KTL Cyclones, and 2.0 µm pore size Teflon-coated glass fiber filter

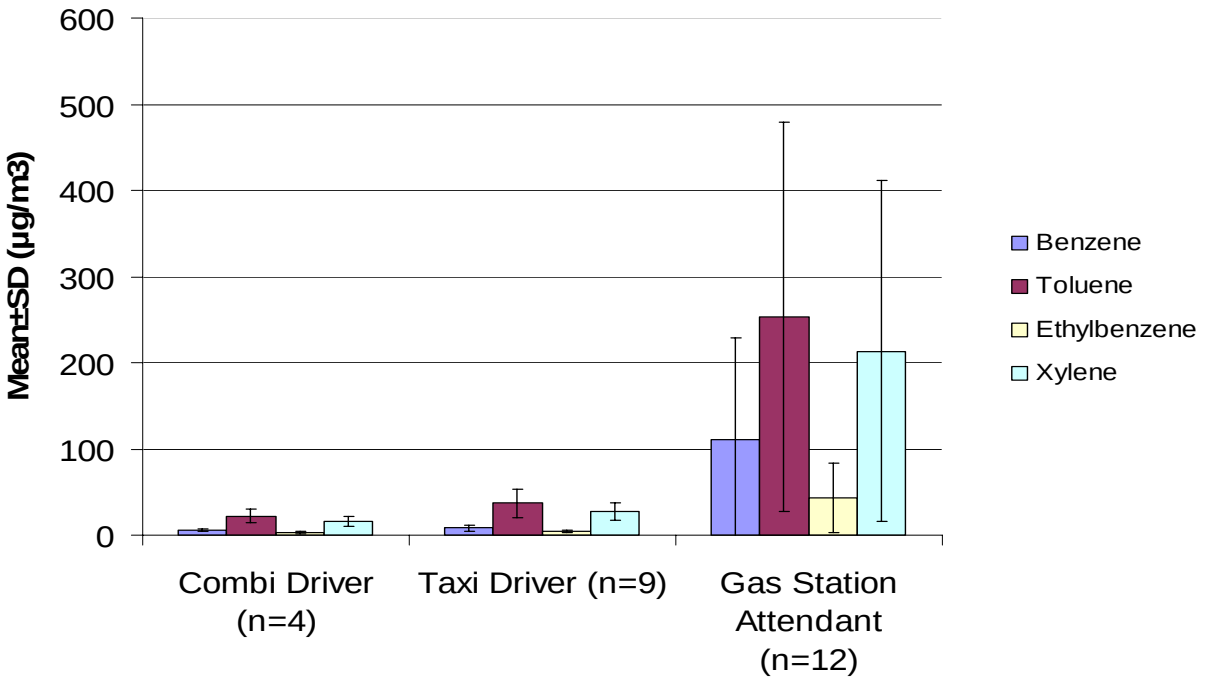

Figure 4 Occupational exposures to benzene, toluene, ethylbenzene, and xylene (BTEX) among combi drivers, taxi drivers, and gas station attendants collected by a diffusive steel tube containing Tenax as adsorbent and analyzed by a thermal-desorption system coupled to a gas chromatograph with a mass spectrometer (GC-MS)