

Comparison of air pollution exposure for five commuting modes in Sydney – car, train, bus, bicycle and walking

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Introduction

Motor vehicles emit a variety of air pollutants that are known to be associated with adverse health effects. Common air pollutants emitted by motor vehicles include fine particles, nitrogen dioxide and volatile organic compounds (VOCs). Exposure to fine particles is associated with short and long-term adverse health effects on the lungs and heart, including premature death.¹ Exposure to nitrogen dioxide is associated with adverse effects on the lungs, particularly irritation to airways and exacerbation of asthma.^{1,2} VOCs include benzene, toluene, ethylbenzene and xylenes (BTEX). These chemical compounds are associated with a range of human health effects, from headaches and eye irritation to cancer.^{1,3,4}

It is well established that the motor vehicle is a principal source

of air pollution in a city such as Sydney.⁵ There is particular concern that a high proportion of personal exposure to carcinogens such as benzene occurs through being in a private motor vehicle while commuting. Investigations in a number of cities around the world have shown that exposure to air pollutants for commuters in motor vehicles is considerably higher than ambient urban concentrations, and higher than concentrations found in other urban transport modes such as train, bus, cycling and walking.⁶⁻¹³ Many of these investigations consider exposure to benzene, toluene, ethylbenzene and xylenes, and several studies have compared commuting exposures to nitrogen dioxide.¹⁴⁻¹⁶

The majority of these studies comparing personal exposure by travel mode focus on fixed routes of travel.⁶⁻¹³ However, this

Abstract

Issue addressed: International studies have consistently found that exposure to air pollutants is higher inside cars than outside. However, few studies have compared personal exposure to air pollutants by travel mode focusing on usual travel patterns.

Objectives: To compare the exposure to benzene, toluene, ethylbenzene and xylene (BTEX) and nitrogen dioxide (NO₂) for commuters in central Sydney for five different commuting modes.

Methods: Forty-four volunteers were recruited into one of five travel mode groups: car, train, bus, bicycle and walking. Each participant travelled for at least 30 minutes by their usual mode of travel to the area around Royal Prince Alfred Hospital, in central Sydney. Each participant wore BTEX and NO₂ passive sampling apparatus during their travel to and from work for two weeks, following specific instructions to measure personal exposure.

Results: The highest pollutant levels for all four BTEX pollutants were found for car commuters. Train commuters recorded the lowest pollutant levels for all four BTEX pollutants and NO₂, and these levels were significantly lower than that for car commuters. Commuting by bus recorded the highest levels for NO₂. Walking and cycling commuters had significantly lower levels of exposure to benzene compared with car commuters and significantly lower levels of NO₂ than bus commuters.

Conclusions: The results of this study are consistent with the findings of studies in other cities and found elevated levels of exposure to motor vehicle-related pollutants in roadway microenvironments. Strategies that encourage commuting by train, walking and cycling should be supported as this reduces population exposure to motor vehicle-related pollutants.

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So what?

People travelling to work in peak-hour periods should use alternatives to cars to reduce their exposure to air pollutants, and also to reduce the exposure of other commuters by reducing their contribution to car emissions.

approach may not necessarily reflect the usual travel patterns of the population and the associated level of exposure that commuters may experience. This study therefore compares personal exposure to BTEX and nitrogen dioxide for five urban transport modes for commuters travelling to and from work at a location near the CBD, regardless of route taken.

Methods

This is a cross-sectional analytical study to compare exposure to benzene, toluene, ethylbenzene and xylene and nitrogen dioxide (NO₂) by five common travel modes – car, train, bus, bicycle and walking. Participants wore BTEX and NO₂ passive samplers during their travel to and from work for two weeks (Monday to Friday) following a specific sampling protocol. At the end of the first week, the BTEX and NO₂ samplers were collected for analysis and replaced by new samplers. The study was undertaken from 13-27 September 2002. Each week's exposure sample represents an average of 10 half-hour or longer exposures during travel to and from work time periods, which are summarised as a geometric mean.

Sample population

A convenience sample of 44 participants who commuted to work using one of the five modes of transport was recruited for the study. Study participants were staff of the Central Sydney Area Health Service based at or near the Royal Prince Alfred Hospital. Participants were required to be non-smokers, travel for a minimum of 30 minutes to and from work, and to follow specific instructions when using the BTEX sampler tube and NO₂ sampler.

The Royal Prince Alfred Hospital is located in the suburb of Camperdown, three kilometres from the Sydney CBD. This study location was selected as highly suitable as it is accessible by all transport modes considered in the study, and is a large employer.

Sample collection and analysis

Volunteer participants were required to travel directly to and from work for the period of the study, and use one mode of transport for the entire period. Volunteers were trained in the use of sampling equipment and provided written information on how to activate and deactivate the passive samplers and secure and store the samplers when not in use. Sampling equipment was only activated while the participant was commuting by their selected mode. For instance, a train commuter deactivated their samplers when arriving at the station platform, thereby not exposing the samplers for the connecting walk from platform to work or home. Air-tight plastic vials were provided to seal and store the NO₂ samplers, and Teflon caps to seal the BTEX samplers. Volunteers were provided with diary sheets to record start and end time of journeys and encouraged to record any unusual circumstances in their journey. Sampling

occurred in all commuters on the same days to control for variation in background ambient air pollution levels.

All samplers were developed and provided by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Division of Atmospheric Research (CSIRO-DAR). Technicians in CSIRO were blinded to the travel mode of the volunteer and analysed all samples. Technical details on the measurement of BTEX and NO₂ and the analyses used by the CSIRO can be obtained from the authors on request.

Commuting mode

Cars used in the study were a range of petrol-fuelled sedan models manufactured from 1997. Train mode commuting was undertaken on the NSW CityRail network and bus mode commuting was on the State Transit Authority service.

Statistical analysis

The distribution of BTEX and NO₂ results indicated that the data were skewed. Logarithmic transformation of the raw data produced more normally distributed data, and all subsequent analyses used the log-transformed data. Geometric means were calculated. A repeated measures ANOVA model was used to analyse the data, with SPSS v10.1 for Windows statistical software package. This analysis approach was taken to allow for the statistical adjustment of the data for minor differences in mean exposures between weeks one and two.

The data were examined for possible outliers by identifying data that were three standard deviations away from the mean. The data were also visually examined using box-plots and any data points at 1.5 inter-quartiles away from the first and third quartile were identified. Eight data points from four cases were defined as outliers and excluded from subsequent analyses using these criteria. Sensitivity analysis (repeating the analysis with and without the outliers) identified that their exclusion made no difference to the conclusions of the study.

Results

The nine participants travelling by car travelled, on average, for 403 minutes each. The five participants in week 1 and three in week 2 travelling by bus, travelled on average for 276 minutes each. The 11 participants travelling by train travelled, on average, for 331 minutes each. The seven participants in week 1 and eight participants in week 2 who cycled travelled, on average, for 351 minutes. The 10 participants walking in week 1 and eight participants in week 2 walked for an average of 299 minutes.

Car commuters received the highest average exposure to benzene, toluene, ethylbenzene and xylene of any of the commuting modes. Bus commuters had the highest average exposure levels to NO₂. Train commuters recorded the lowest

Table 1: Adjusted geometric means of all variables by transport mode.^a

| Mode (n) | Benzene (parts per billion) | p value | Toluene (parts per billion) | p value | Ethyl benzene (parts per billion) | p value | Xylenes (parts per billion) | p value | NO ₂ (parts per billion) | p value |
|----------------|-----------------------------|---------|-----------------------------|---------|-----------------------------------|---------|-----------------------------|---------|-------------------------------------|---------|
| Car (n=9) | 12.29 | Ref | 28.76 | Ref | 4.38 | Ref | 19.91 | Ref | 29.70 | 0.042 |
| Bus (n=4) | 6.94 | | 22.47 | | 4.00 | | 15.18 | | 44.30 | Ref |
| Cycle (n=7) | 6.17 | 0.032 | 24.56 | | 2.72 | | 12.16 | | 24.58 | 0.005 |
| Train (n=11) | 3.77 | <0.001 | 12.44 | | 1.73 | 0.002 | 7.26 | 0.001 | 14.85 | <0.001 |
| Walk (n=9) | 5.70 | 0.014 | 19.71 | | 2.96 | | 13.11 | | 26.08 | 0.011 |
| Overall F-test | 5.062 | 0.003 | 1.825 | 0.221 | 3.467 | 0.019 | 3.367 | 0.022 | 15.895 | <0.001 |

(a) Adjusted for week of data collection.

Ref= reference value for statistical significance testing.

exposure levels for all four BTEX pollutants and NO₂. Walking and cycling commuters had significantly lower levels of exposure to benzene compared with car commuters and significantly lower levels of NO₂ than bus commuters.

After excluding outliers and adjusting the data for minor differences between the two weeks of data collection, significant differences between commuting modes for all pollutants except toluene were found (see Table 1). The concentration levels found for train commuting were significantly lower than for car commuting, for all BTEX pollutants except toluene.

Figure 1 shows the ratios or relative concentrations of BTEX levels across the modes using the train mode as the reference category. Total BTEX concentrations provided in the last column demonstrate well the elevated levels found in cars, compared with other modes.

Discussion

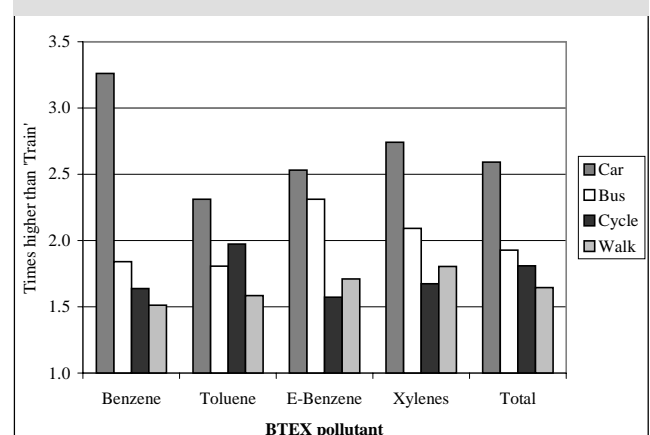
We have confirmed the findings from other cities that average BTEX concentration levels in cars are higher than in other commuting modes. Benzene concentration levels measured in cars were more than three times higher than in trains. While the levels of BTEX found in cars are unlikely to be associated with acute health effects, there is some concern related to long-term exposure to these chemicals.¹ Benzene in particular is a carcinogen, and it is recommended that exposure to carcinogens be as low as possible. Estimating benzene exposure over 40 years of typical commuting,¹⁷ a motorist would inhale 411mg of benzene compared with 126 mg for a train commuter (see footnote 1). Our results indicate the actual exposure of participants given the commuting mode they use and the time taken. Shorter trips would likely reduce individual exposure, but actual exposure reflects commuting requirements.

Footnote 1: Assuming 79 mins/day,¹⁷ 5 days/week, 48 weeks for 40 years, adult respiratory rate 0.83 L/min (after Wadge & Salisbury, National Environmental Health Forum Monograph, 1997¹⁹).

There are a number of potential explanations as to why BTEX levels are significantly higher in cars compared with other modes. Some authors have suggested it is attributable to the car travelling in a “tunnel of pollutants”, as the main source of air intake to a car is from the roadway stream of traffic where there is a high concentration of these pollutants from the exhaust of all the vehicles on the road.¹⁶ Another explanation is direct contamination from the motor vehicle itself.^{8,10,11,18} The differential effect we found for peak BTEX (in cars) and NO₂ (in all roadway modes) tends to confirm this second point, as BTEX gases come from both evaporative and combustive emissions, whereas NO₂ is generated only after combustion. While all road users are exposed to combustive emissions, occupants of cars may have an additional exposure to evaporative emissions directly from their own car that does not directly impact on other road users.

In comparing total BTEX exposure the lowest levels were clearly found for train commuters, followed by walking, cycling and bus. This suggests that a non-roadway mode and modes involving physical activity are good alternatives to cars to reduce personal exposure to BTEX pollutants. Walking and cycling are likely to

Figure 1: Relative BTEX concentrations across modes with ‘Train’ mode as baseline.



be most beneficial when routes are away from busy car routes, although even on the same roadway and taking into account increased respiration due to activity, cyclists in Amsterdam still had 2-3 times lower exposure to pollutants than car drivers.²⁰ The clearly lower exposure levels for train commuters is likely to have resulted from the commuter not being directly in a roadway microenvironment, and therefore this result supports the “tunnel of pollutants” finding for roadway-based modes.

We found that only train commuters had considerably lower levels of exposure to NO₂ compared with other modes. Bus commuters were found to have considerably higher levels of NO₂ exposure compared with other modes, but it is unclear why this occurred. Motor vehicle, bicycle and walk modes measured NO₂ exposure concentrations of between 24 and 30 ppb. Overall, these results may have been strongly influenced by the study location being close to the Sydney CBD where ambient NO₂ levels are much higher than the rest of the city, especially for peak hour times.

The focus of this study was on usual travel patterns, and therefore is most likely to reflect an ‘average’ level of exposure for commuters using the different travel modes. The passive samplers used in this study measured total exposure for the sampling period, standardised for duration of travel. That the relative pollutant exposures across modes are consistent with other studies where specific routes have been examined by mode suggests that it is not so much the route that is important, but the mode.

We were not able to determine the proportion of total pollutant exposure contributed by commuting to and from work, as we did not measure total daily exposure, and it is not clear if our participants can be compared with national data. Driving for 10 minutes compared with walking for 30 minutes may expose the driver to a higher level of exposure but for a shorter time. However, we did not measure ‘door-to-door’ exposure in all environments related to the travel mode, including parking lots (which can be very high), or that associated with refuelling, which also increases exposure.

The study was limited by the fewer number of participants on the bus mode compared with other modes. This made it difficult to test whether differences between this mode and others were statistically significant. The higher level of NO₂ measured for the bus mode compared with other modes may have arisen due to participants commuting on heavily trafficked routes leading in and out of the CBD during peak hour. This is supported by a study conducted in Amsterdam, which found that for a given mode NO₂ concentrations were significantly influenced by the route taken.¹⁴

To further investigate commuter exposures in and out of roadway microenvironments, a comparative study for bus and bicycle modes could be undertaken for selected fixed routes. There is

good opportunity to do this in some parts of Sydney since the recent opening of the Western Sydney bus transitway, a dedicated roadway for buses.

The results from this study are one component of information people can use in making their travel choices and the relative pollutant exposure levels they are likely to experience with those choices, although there are many factors influencing travel choices. These results do have implications for transport planning. To minimise the exposure of the population to air pollutants, the greater provision of commuting alternatives to cars should be a primary planning objective.

Further, the commuter exposure data are consistent with NSW Environment Protection Authority data⁵ indicating that cars and other motor vehicles are generating considerable volumes of air pollutants that directly and adversely impact upon other commuters and the population in general. Strategies to reduce air pollutant exposure by reducing car use were included in *Action for Air*, the NSW Government’s 25-year air quality management plan. The actions include providing convenient, safe, clean and affordable alternatives to the motor vehicle, and developing a metropolitan parking policy to make cars less convenient. Elsewhere, other strategies have been trialled, such as congestion charging (a surcharge for driving into the city in London and other European cities²¹), bus priority lanes and higher registration costs for cars for personal use.²²

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