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The Science of the Total Environment 279 (2001) 131–136

the Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Man

www.elsevier.com/locate/scitotenv

Differences in cyclists and car drivers exposure to air pollution from traffic in the city of Copenhagen

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Received 16 August 2000; accepted 5 February 2001

Abstract

It has frequently been claimed that cycling in heavy traffic is unhealthy, more so than driving a car. To test this hypothesis, teams of two cyclists and two car drivers in two cars were equipped with personal air samplers while driving for 4 h on 2 different days in the morning traffic of Copenhagen. The air sample charcoal tubes were analysed for their benzene, toluene, ethylbenzene and xylene (BTEX) content and the air filters for particles (total dust). The concentrations of particles and BTEX in the cabin of the cars were 2–4 times greater than in the cyclists' breathing zone, the greatest difference being for BTEX. Therefore, even after taking the increased respiration rate of cyclists into consideration, car drivers seem to be more exposed to airborne pollution than cyclists.

Keywords: Traffic; Air pollution; Benzene exposure; Car driver; Cyclist

1. Introduction

In Denmark, as in most other countries, the number of cars is increasing and so is the concern about the impact on human health caused by traffic related emissions. Obviously, it is important to obtain knowledge of the amount of the most hazardous air pollutants from car exhaust, and considerable effort has already gone into monitoring the concentrations of these chemicals in urban air (Raaschou-Nielsen et al., 1996; Jo and Choi, 1996; Duffy and Nelson, 1997; Fromme et al., 1997).

Exposure to the pollutants affects different types of road users, and among these, car drivers

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0048-9697/01/$ - see front matter
PII: S0048-9697(01)00758-6

are of special interest, because many people spend several hours every day inside an automobile. Volatile organic compounds have been measured in car cabins and it was found that the inside-car concentrations were much higher than the outdoor concentrations (Weisel et al., 1992) and the concentrations in buses (Jo and Choi, 1996). They were also higher than those found in a subway train (Fromme et al., 1997/98).

Personal air sampling has been used in a Dutch study, where CO, NO_2, benzene, toluene, xylenes and PAHs were sampled on people either driving a car or riding a bicycle (van Wijnen et al., 1995). The study took place in Amsterdam, where cyclists and car drivers took the same routes through the city. The measurements showed that the exposure levels were greater for the car drivers than for the cyclists. Moreover, a Danish study using personal air sampling of children's exposure to volatile organic compounds, showed a highly significant correlation between exposure to benzene and time spent in a car (Raaschou-Nielsen et al., 1997).

The main purpose of the present study was to compare the exposure levels of four aromatic hydrocarbons, benzene, toluene, ethylbenzene and xylenes (BTEX) and particulate matter for car drivers and cyclists, respectively, while taking the same route in the traffic of Copenhagen.

2. Methods

2.1. Field study

A field pilot study was conducted using cyclists and car drivers equipped with two air sampling pumps: one with a charcoal test tube and one with an air filter. Two teams of two cyclists and two car drivers drove a slow 7.6-km route (< 30 km/h average speed) through inner Copenhagen for 4 h in the morning hours: 07.40–09.40 h and 10.00–12.00 h, on two dates in the summer 1998: 18 June and 3 August. Both cars used were typical B-class vehicles from the 1990s (VW Vento and Fiat Brava). None of them used the air vent recirculation option during the experiment.

Table 1
Meteorological data from the 2 sampling days

		18 June	3 August
Wind velocity (10 m height)	m/s	8.5	1–3
Wind direction		W	NW–E
Temperature	°C	13.3	14
Air pressure	Pa	1017	1024
Humidity	%	61	90 → 70

2.2. Meteorological data

Meteorological data (Table 1) were obtained from the measuring station situated at Kastrup Airport in Copenhagen.

2.3. Air sampling

All sampling equipment came from the Danish Technological Institute. The air sampling pumps were adjusted to a flow of 1.9 l/min immediately before the start of the experiment. The tubes and the filters were placed close to the breathing zone of the car drivers and the cyclists. For the cyclists, they were positioned on the chest and in the cars they were positioned at the top of the back on the drivers seat.

2.4. Chemical analysis

Vapours of benzene, toluene, ethylbenzene and xylenes (BTEX) were collected on a gas sampling charcoal tube at a flow of 1.9 l/min. The detection limit of the method was 0.05–0.1 μg/compound. BTEX were analysed in a gas chromatographic/mass spectrometric method, using selected ion monitoring. Total particulate matter was analysed gravimetrically after sampling on a membrane filter at a flow rate of 1.9 l/min. The filter used was Millipore Celluloseacetate, 37 mm in diameter and 0.8 μm pore size. The detection limit for total dust was 10 μg/filter.

2.5. Statistical method

Data were analysed in a three-way ANOVA design without interaction terms. The dependent variables were as follows: concentrations of benzene, concentrations of toluene, concentrations of ethylbenzene and xylenes, concentrations of total hydrocarbon and concentrations of particles (total dust). The independent variables were: date of sampling (two levels), mode of transport (two levels) and car make (two levels nested in mode of transport).

3. Results

Table 1 shows the meteorological data for the 2 sampling days. The temperature and the air pressure were very similar for the 2 days. The most significant difference was that the wind velocity was highest on the sampling day in June.

The samplings were carried out both in the morning rush hour and late morning. Data, describing the sampling conditions, are shown in Table 2. The average speed for the cars was low during the morning rush hours (17.8 ± 2.3 km/h) and very similar to the speed for the cyclists (14.6 ± 0.3 km/h). However, in the late morning the cars drove faster, and the difference in speed between the cars (24.1 ± 2.3 km/h) and the bicycles (15.4 ± 0.3 km/h) was more significant.

The results of BTEX and particle measurements are given in Table 3. The benzene concentrations were in the range 11.0–17.5 $\mu g/m^3$ in the cabins and 4.5–5.6 $\mu g/m^3$ in the breathing zone of the cyclists, giving approximately three times higher exposure for the car drivers than the cyclists. The air concentrations of toluene and ethylbenzene/xylenes were approximately four times higher than the benzene concentrations, and the exposure of the car drivers for these chemicals were also approximately three times higher than the exposure of the cyclists. The same pattern can be seen for the particulate matter, although the ratio between the exposure of drivers and cyclists is only approximately a factor of two. The results from 18th June showed a significant difference in the concentrations of all pollutants between the two cars. The VW had the vent in a higher position on this day, which may explain the lower concentrations measured inside this car due to more efficient ventilation.

Table 4 shows the results from the analysis of variance (ANOVA). In all of the tests, the concentrations were significantly dependent on the mode of transport, whereas no significant differences could be observed between the two makes of car. Another significant result was that the level of particulate matter was higher on the first sampling day ($P = 0.009$), while none of the hydrocarbons showed a dependency upon the sampling date. The explanation for this phenomenon could be that on this day in June, where the wind velocity was 8.5 m/s, the dust in the streets could have been whirled around more than on the day in August, where the velocity of the wind was only 1–3 m/s (Table 1).

Table 2
Bicycling and driving data for the 2 sampling days

Date	Period		Time (min)	Rounds (7.6 km)	Speed (km/h)		Time (min)	Rounds (7.6 km)	Speed (km/h)
18 June	Rush hour	VW	120	4	15.2	Cyclist 1	120	4	15.2
		Fiat	114	4	16.0	Cyclist 2	120	4	15.2
	Late morning	VW	120	6	22.8	Cyclist 1	113	4	16.1
		Fiat	105	6	26.1	Cyclist 2	113	4	16.1
3 August	Rush hour	VW	115	5	19.8	Cyclist 1	130	4	14.0
		Fiat	113	5	20.2	Cyclist 2	130	4	14.0
	Late morning	VW	120	6	22.8	Cyclist 1	125	4	14.6
		Fiat	110	6	24.9	Cyclist 2	125	4	14.6
	Rush hour, average				17.8 ± 2.3				14.6 ± 0.3
	Late morning, average				24.1 ± 2.3				15.4 ± 0.3

Table 3
Concentrations of BTEX and particles (total dust) sampled on 2 different days in the city of Copenhagen, 1998

Pollutant	Date	Car	$\mu g/m^3$	Bicycle	$\mu g/m^3$
Benzene	18 June	VW	11.0	Bicycle 1	5.4
		Fiat	17.5	Bicycle 2	5.4
	3 August	VW	15.5	Bicycle 1	5.6
		Fiat	13.7	Bicycle 2	4.5
Toluene	18 June	VW	41.2	Bicycle 1	20.6
		Fiat	82.9	Bicycle 2	19.4
	3 August	VW	77.0	Bicycle 1	22.9
		Fiat	76.0	Bicycle 2	19.6
Ethylbenzene and xylenes	18 June	VW	42.8	Bicycle 1	9.9
		Fiat	72.6	Bicycle 2	18.7
	3 August	VW	73.9	Bicycle 1	23.3
		Fiat	77.6	Bicycle 2	20.4
Particles, total dust	18 June	VW	88	Bicycle 1	68
		Fiat	120	Bicycle 2	68
	3 August	VW	45	Bicycle 1	21
		Fiat	47	Bicycle 2	21

4. Discussion

Road users are exposed to many hazardous chemicals, which are types of traffic related air pollution. The most important parameters are BTEXs, PAHs, NO_x, CO, 1,3-butadiene and particles (van Wijnen and van der Zee, 1998), and among these we have measured BTEX and particulate matter using personal air samplers.

Exposure to particulate air pollution can cause severe health problems. McConnell et al. (1994) observed a positive association between PM_{10} and bronchitis in children with a history of asthma in southern California, and recently Pope III et al. (1999) showed a dose-relationship between PM_{10} concentrations and daily mortality in Utah.

Among the BTEX compounds, benzene is considered to be the most hazardous. Benzene is a well-known carcinogen (WHO, 1993) and among all the volatile organic compounds related to traffic, it is the chemical of most health concern (Guerra et al., 1995; Fromme, 1995). We consider BTEX to be a good indicator of exhaust gases from gasoline engines, while particles originate from various sources of combustion and, therefore, indicate a less specific pollution. Furthermore, the ratio of exposure between car drivers and cyclists was found to be approximately two times higher for BTEX compared to particulate matter (Table 4). Therefore, we consider the benzene results of the present study to be of the greatest significance, and these are thus discussed in further detail in the following.

In a comprehensive review by van Wijnen and

Table 4
Results from ANOVA analysis

	Car $\mu g/m^3$		Standard error of estimates, $\mu g/m^3$	P	Car/bicycle ratio
Benzene	14.4	5.2	1.1	0.004	2.8
Toluene	69	21	6	0.004	3.4
Ethylbenzene and xylenes	67	18	4	0.001	3.7
Hydrocarbons	215	58	9	0.0002	3.7
Particles (total dust)	75	44	4	0.007	1.7

van der Zee (1998) many studies of volatile organic compounds are reported which showed higher in-vehicle concentrations than were found in the ambient air. In-car concentrations of benzene in three American cities were in the range of 10–17 μg/m^3. This is very close to those found in our study, while in-vehicle concentrations in Amsterdam were much higher with a variation of 43–74 μg/m^3. In another review of Gennart et al. (1994), results from studies of in-vehicle benzene concentrations showed much higher concentrations than this study. Thus, driving in dense traffic in Sweden showed concentration levels of 100–200 μg/m^3, and when queuing the concentrations reached 200–400 μg/m^3. Higher concentrations of benzene within a car compared to the ambient air were found in a study by Weisel et al. (1992), who estimated that the difference was up to 50 times higher inside the cabin than outside.

The great variations of benzene concentrations in the above mentioned studies could be due to many factors, the most important being the concentration of benzene in gasoline. When this study was carried out, the benzene concentration of gasoline allowed was up to 5 mg/l, while the limit value shortly after the study was lowered to 1 mg/l to comply with new EU regulations. Other factors may also influence the in-vehicle benzene concentrations. Duffy and Nelson (1997) showed in a study carried out in Sydney that the age of the cars is of great importance. They found in-car concentrations of old cars (pre-1986 without catalyst equipment) to be twice as high as in newer cars. Römmelt et al. (1999) found that the BTEX concentrations in the streets of Munich decreased significantly during the years 1993–1997, indicating that the replacement of old cars may influence the concentrations of the volatile aromatics.

The study by van Wijnen et al. (1995) showed a respiratory average of 2.3 times higher for the cyclists compared with the car drivers. By using this factor, we have calculated that car drivers still get twice as much benzene (0.2 μg/min) into their lungs than bikers (0.1 μg/min). It could be argued that car drivers are exposed to a lesser degree due to a higher speed. However, our results show that during the rush hours, the speed of the car drivers is very similar to the speed of the cyclists. Moreover, children transported on the back of a bicycle may inhale a lower concentration of pollutants than they would inside a car, because they, as passive passengers, exhale the same amount of air in the two situations.

Concern for small children as road users is important, taking into consideration that benzene can cause leukaemia, and that leukaemia can be correlated with car ownership (Wolff, 1992). Furthermore, a study by Savitz and Feingold (1989) has shown that childhood cancer can be correlated with traffic density and Nordlinder and Järvholm (1997) found that car density could be correlated with acute myeloid leukaemia in children and young adults.

Among the pollutants analysed in the present study, benzene is the only compound that may cause adverse effects in the measured concentrations. WHO (1995) has established a life-span risk of cancer over 70 years of one cancer observation per million people at 0.13–0.23 μg/m^3. The actual measurements are 5–14 μg/m^3, i.e. at least 40–50 times above this concentration.

5. Conclusion

On the basis of this study, we can conclude that cyclists in the city of Copenhagen are exposed to lower concentrations of traffic related pollutants than car drivers. Furthermore, we conclude that car drivers experience 3–4 times higher BTEX concentrations and approximately two times higher exposure of particles than bikers. The study also indicates that the air children breathe may be better on the back of a bicycle than inside a car.

Acknowledgements

The authors wish to thank Lykke Enøe and Anne-Grethe Winding, who assisted the experimental planning and sampling, and Henrik Demant, Jesper K. Hansen, Dennis Madsen and Jacob Turman, who participated in the field study. The Danish Ministry of Transport funded the study.

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