

Volatile Organic Compound Exposure of Suburban Elementary Students in Taiwan

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Occupational studies indicate that exposure to high-level benzene can result in a leukemogenic effect (International Agency for Research on Cancer [IARC], 1982; IARC, 1987). In fact, the health effects of volatile organic compounds (VOCs) include immune effects (e.g., asthma and allergy), cellular effects (e.g., cancer), cardiovascular effects, neurogenic and sensory effects, and some respiratory effects other than immunologic effects (Molhave, 2003). Besides industries and occupational sources, VOCs can be released from various sources including vehicles, environmental tobacco smokes, personal laser printers, and the like (Hsu et al., 2005; Molhave, 2003). Versatile sources of VOCs probably lead to the larger uncertainties when personal exposure is estimated on the basis of source intensity. Thus, personal sampling and biomarker measurements are used for accurate determination of personal exposure to toxic substances.

Studies on personal exposure to VOCs by personal sampling have been reported extensively in recent decades (Edward et al., 2001; Han and Naeher, 2006; Kim et al., 2002; Kinney et al., 2002; Ortiz et al., 2002). However, most studies have focused on the adult population or commuters. Children are considered more susceptible to hazardous pollutants (Aprea et al., 2000; Guzelian et al., 1992). Thus the concern about

the relationship between children's exposure to chemicals and their adverse health effects has been growing (Pearson et al., 2000). Automobile exhaust is reported to be associated possibly with childhood cancers including leukemia (Pearson et al., 2000). In Taiwan, no personal VOC exposure data on children are available to date. Additionally, the reported personal VOC exposure of commuters was much higher than for those in other counties (Chan et al., 1994; Kuo et al., 2000). This study therefore aimed to collect personal samples of elementary students for estimation of their current environmental VOC burden so their health can be further protected with appropriate measures.

Materials and Methods

A total of 41 fifth-grade elementary school students were recruited into this study. These students occupied a school located in a suburban area about 7 km west of the Hsin-Chu scientifically based industrial park. Every student wore a Shibata passive sampler (Shibata Scientific, Japan) on the collar for 48 h in November, 2005, except when taking a shower or sleeping, at which time the sampler was put as close to the individual as possible. This sampler used a porous tetrafluoroethylene (PTFE) tube packed with granular activated charcoal, and its sampling rate was approximately 50 mL/min (Olansandan and Matsushita, 1999). The collected VOCs were extracted with 2 mL of carbon disulfur (Spectro grade, >99.9%, Riedel-de-Haen, Seeize) then ultrasonicated at room temperature for 1 h. The solvent was centrifuged at 6,000 rpm for 10

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min at room temperature, after which 1.5 mL of supernatant was transferred into autosampler vials for analysis by gas chromatography with a mass spectrometer (Agilent Technology 6890N Network GC System, Agilent 5973 Network Mass Selection Detector, Column: HP-5MS).

The operating conditions were as follows: injection temperature (200°C), flow rate (1 mL/min), oven temperature (40°C for 3 min initially, then 3°C/min to 100°C followed by 20°C/min to 200°C and held for 5 min). The amount of benzene, toluene, ethylbenzene, m-xylene, and o-xylene were quantified by comparisons with the calibration curves (Spectro-grade, >99.9%, Fluka, Switzerland) generated by standard solutions of these agents at various concentrations (approximately 0.35–7.0 µg/mL). The correlation (R^2) of calibration curves for BTEX were 1.00 (benzene), 0.987 (toluene), 0.979 (ethylbenzene), 0.998 (m,p-xylene), and 0.999 (o-xylene), respectively. The instrument detection limits were calculated according to three standard deviations of seven replicate measurements of the lowest calibration concentrations for benzene (0.376 µg/mL), toluene (0.174 µg/mL), ethylbenzene (0.120 µg/mL), m-xylene (0.100 µg/mL), and o-xylene (0.192 µg/mL). Three field blanks and two reagent blanks were conducted to estimate the possible contaminations during sampling and analysis.

To understand the recovery of benzene, toluene, ethylbenzene, m-xylene, and o-xylene from samplers, three spiked samples were conducted, extracted, and analyzed as described earlier except for the sampling process. Approximately 18 µg each of benzene, toluene, ethylbenzene, m-xylene, and o-xylene (Spectro-grade, >99.9%, Fluka, Switzerland) was spiked. These spiked samples ($n = 3$) were extracted and analyzed using the same procedure as for the real samples. The recoveries were $98.3\% \pm 2\%$ for benzene, $98.9\% \pm 8.5\%$ for toluene, $101.1\% \pm 2.3\%$ for ethylbenzene, $59.5\% \pm 10.6\%$ for m-xylene, and $93.6\% \pm 3.1\%$ for o-xylene. The recovery of m-xylene (59.5%) was used to adjust the concentration of m-xylene, whereas the others were not adjusted.

Results and Discussion

Of the 41 students, 36 (18 boys and 18 girls) provided comprehensive samples for further analysis. The average concentrations with standard deviations were 6.48 ± 3.30 µg/m³ for benzene, 14.68 ± 7.82 µg/m³ for toluene, 9.80 ± 0.42 µg/m³ for ethylbenzene, 10.02 ± 4.29 µg/m³ for m,p-xylene, and 4.00 ± 1.42 µg/m³ for o-xylene. The BTEX exposures of elementary

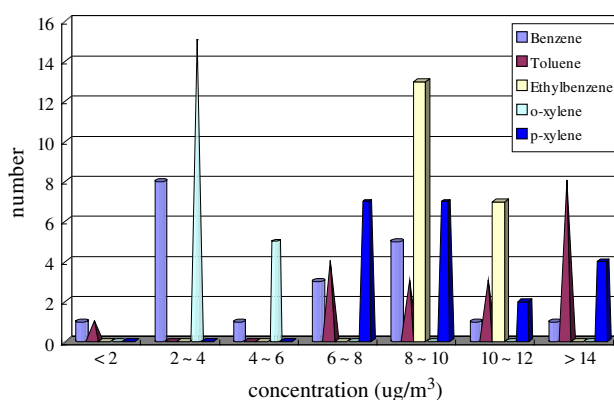


Fig. 1 Profile of boys' personal exposure to BTEX

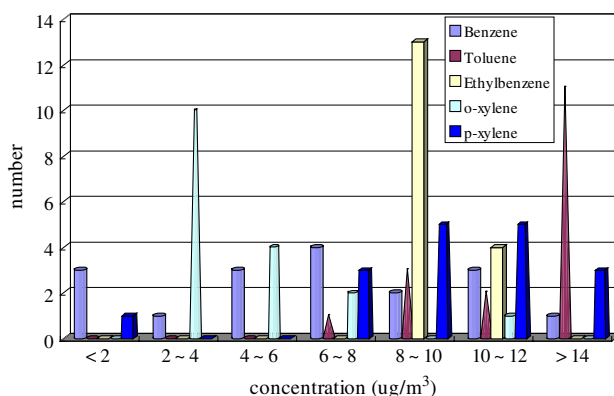


Fig. 2 Profile of girls' personal exposure to BTEX

boys and girls were very similar (Figs. 1 and 2), probably because most elementary students in the same grade have a similar life pattern.

As compared with the reported personal BTEX exposure levels (Table 1), our results indicate that the personal BTEX exposure levels for elementary students in Taiwan are higher than for those living in other countries, particularly, benzene exposure levels. The personal BTEX exposure of adults is significantly affected by occupational exposure, which may greatly elevate their personal exposure to BTEX (Edwards et al., 2001; Son et al., 2003). Smoking behavior, including passive smoking, was proven to elevate personal exposure to BTEX (Park and Jo, 2004).

In general, the levels of personal exposure to BTEX were not statistically correlated ($p > 0.5$) with each other, except for m,p-xylenes, and all the others. This observation implies that these students were exposed to quite heterogeneous sources releasing BTEX. In addition, each source might emit m,p-xylenes.

Furthermore, the correlation between m,p-xylenes and the sum of BTEX is significant ($R^2 > 0.75$). Therefore, this compound may serve as a good indi-

Table 1 Personal BTEX exposure levels ($\mu\text{g}/\text{m}^3$)

Subject	Area		Benzene	Toluene	Ethylbenzene	m,p-Xylene	o-Xylene	Reference
Children	Minneapolis	Summer	4.8	27.6		6.3	2.5	Adgate et al., 2004b
Children ^a	Minneapolis	Winter	2.1	7.7	1	3.5	1.1	Adgate et al., 2004a
		Spring	1.5	7.7	0.9	2.9	1	
General population	Helsinki		3.40 ± 5.40	25.33 ± 48.18	7.69 ± 47.02	24.98 ± 145.68	10.05 ± 65.24	Edwards et al., 2001
General population	Birmingham	Day	10.6	28.9	3.0	10.3	3.1	Kim et al., 2002
		Night	9.3	47.0	2.7	83	2.2	
High school	New York	Winter	4.70 ± 3.33	15.5 ± 2.37	2.24 ± 2.37	6.71 ± 5.69	2.24 ± 2.09	Kinney et al., 2002
Students		Summer	3.09 ± 1.94	37.4 ± 60.5	2.37 ± 2.02	10.9 ± 6.8	3.93 ± 2.33	
General population	Oxford		4.6	34.1	3.2	10	3.7	Lai et al., 2004
Children	Daegu	Nonsmoker	4.45	111.48		17.68	6.3	Park and Jo, 2004
	Passive smoker	6	120.18		25.13	10.13		
Children ^b	Copenhagen	Spring	5.4	27		17		Raaschou-Nielsen et al., 1997
	Rural area	Spring	4.5	10		13		
Nonsmoking adult	Minneapolis		7.6	30.3	5.6	21	6.8	Sexton et al., 2004
General population	Mexico city		1.38 ± 14.3	113.1 ± 95.6	12.6 ± 19.1	42.6 ± 69.8	15.9 ± 28.4	Serrano-Trespalcacios et al.,
General population	Asan	Summer	23.08 ± 0.102	33.12 ± 65.56	1.77 ± 1.79	10.57 ± 7.63	11.43 ± 11.87	Son et al., 2003
	Seoul	Summer	41.22 ± 84.51	193.34 ± 211.76	1.97 ± 2.28	35.49 ± 81.58	39.49 ± 92.25	
Children	Hsin-Chu	Winter	6.48 ± 3.30	14.68 ± 7.82	9.80 ± 0.42	10.02 ± 4.29	4.00 ± 1.42	Current study

BTEX,

^a Median^b Geometric mean

cator of personal, nonoccupational BTEX exposure despite heterogeneous BTEX sources. It is also noteworthy that our samples were collected on the basis of elementary students in a suburban area during winter. Therefore, a more severe exposure scenario can be expected, particularly for those living in an urban and industrial area. Moreover, our data suggest that detailed studies regarding sources of volatile organic compounds are warranted.

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