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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.

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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, Tokyo, 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. Thissampler used a porous trafluoroethylene (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-deHaen, Seeize, Germany) then ultrasonicated at room temperature for 1 h. The solvent was centrifuged at 6,000 rpm for 10 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, ehtylbenzene, m-xylene, and o-xylene were quantified by comparisons with the calibration curves (Spectro-grade, >99.9%, Fluka, Buchs, Switzerland) generated by standard solutions of these agents at various concentrations (approximately 0.35–7.0 µg/mL, Fluka, Buchs, Switzerland). The correlation (R^2) of calibration curves for BTEX (Fluka, Buchs, Switzerland) 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), ehtylbenzene (0.120 µg/mL), m-xylene (0.100 µg/mL), and o-xylene (0.192 µg/mL). Three filed blanks and two reagent blanks were conducted to estimate the possible contaminations during sampling and analysis.

To understand the recovery of benzene, toluene, ehtylbenzene, 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, ehtylbenzene, 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% ± 2% for benzene, 98.9% ± 8.5% for toluene, 101.1% ± 2.3% for ehtylbenzene, 59.5% ± 10.6% for m-xylene, and 93.6% ± 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/m^3 for benzene, 14.68 ± 7.82 µg/m^3 for toluene, 9.80 ± 0.42 µg/m^3 for ethylbenzene, 10.02 ± 4.29 µg/m^3 for m,p-xylene, and 4.00 ± 1.42 µg/m^3 for o-xylene. The BTEX (Benzene, Toluene, Ethylbenzene, Xylenes)exposures of elementary 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.

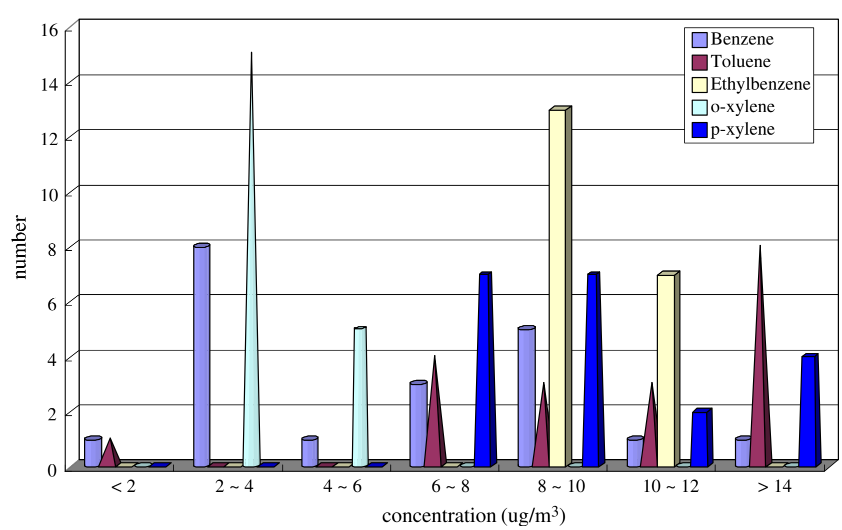

Fig. 1 Profile of boys' personal exposure to BTEX

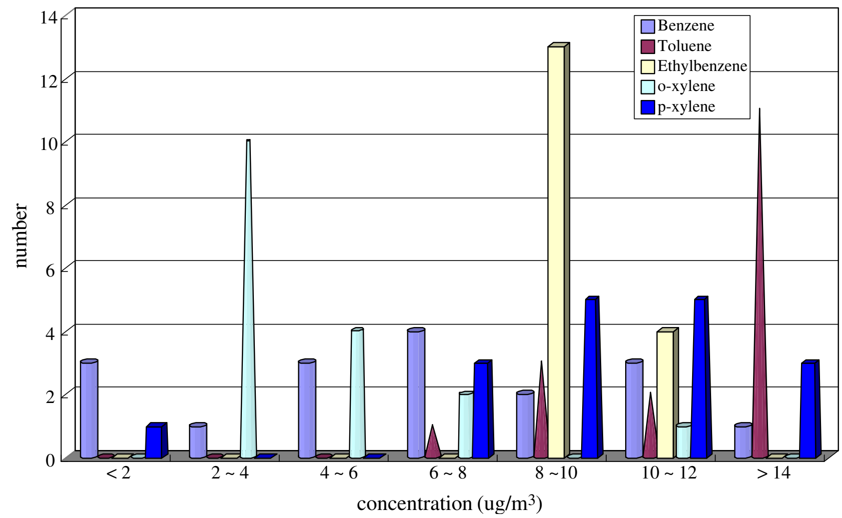

Fig. 2 Profile of girls' personal exposure to BTEX

Table 1 Personal BTEX exposure levels (μg/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 Students	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
		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-Trespalacios et al., 2004
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

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 indicator 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.

References

Adgate JL, Church TR, Ryan AD, Ramachandran G, Fredrickson AL, Stock TH, Morandi MT, Sexton K (2004a) Outdoor, indoor, personal exposure to VOCs in children. Environ Health Persp 112:1386–1392

Adgate JL, Eberly LE, Stroebel C, Pellizzari ED, Sexton K (2004b) Personal , indoor, and outdoor VOC exposure in a probability sample if children. J Expo Anal Env Epid 14:s4–s13

Aprea C, Strambi M, Novelli MT, Lunghini L, Bozzi N (2000) Biological monitoring of exposure to oranophorus pesticides in 195 Italian children. Environ Health Persp 108:521–525

Chan CC, Lin SH, Her GR (1994) Office worker's exposure to volatile organic compounds while commuting and working in Taipei city. Atmos Environ 28:2351–2359

Edwards RD, Jurvelin J, Saarela K, Jantunen M (2001) VOC concentrations measured in personal samples and residential indoor, outdoor, and workplace micronments in EXPOLIS-Helsinki, Finland. Atmos Environ 35:4531–4543

Guzelian PS, Henry GJ, Olin SS (1992) Similarities and difference between children and adults: Implications for risk assessment. ILSI Press, Washington DC

Han X, Naeher LP (2006) A reviewer of traffic-related air pollution exposure assessment studies in the developing world. Environ Int 32:106–120

Hsu DJ, Huang HL, Chien CH, Lin TS (2005) Potential exposure to VOCs caused by dry process photocopiers: Results from a chamber study. Bull Environ Contam Toxicol 75:1150–1155

International Agency for Research on Cancer (IARC) (1982) IARC monographs on the evaluation of the carcinogenic risk of chemicals to human: tobacco smoking. Vol. 38. WHO, IARC

International Agency for Research on Cancer (IARC) (1987) IARC monographs on the evaluation of the carcinogenic risk of chemicals to human: Overall evaluation of carcinogenicity. An updating of IARC Monographs, Volumes 1 to 42. Supplement 7. WHO, IARC, Lyon, France

Kim YM, Harrad S, Harrison RM (2002) Levels and sources of personal inhalation exposure to volatile organic compounds. Environ Sci Technol 36:5405–5410

Kinney PL, Chillrud SN, Ramstrom S, Ross J, Splengler JD (2002) Exposures to multiple air toxics in New York city. Environ Health Persp 110:539–546

Kuo HW, Wei HC, Liu CH, Lo YY, Wang WC, Lai JS, Chan CC (2000) Exposure to volatile organic compounds while commuting in Taichung, Taiwan. Atmos Environ 34:3331–3336

Lai HK, Kendall M, Ferrier H, Lindup I, Alm S, Hanninen O, Jantunen M, Mathys P, Colvile R, Ashmore MR, Cullinan P, Nieuwenhuijsen MJ (2004) Personal exposures and microenvironment concentrations of $PM_{2.5}$, VOC, and NO_2, and CO in Oxford, UK. Atmos Environ 38:6399–6410

Molhave L (2003) Organic compounds as indicators of air pollution. Indoor Air 13:12–19

Olansandan TA, Matsushita H (1999) A passive sampler-GC/ECD method for analyzing 18 volatile organohalogen compounds in indoor and outdoor air and its application to a survey on indoor pollution in Shizuoka, Japan. Talanta 50:851–863

Ortiz E, Alemon E, Romero D, Arriaga JL, Olaya P, Guzman F, Rios C (2002) Personal exposure to benzene, toluene, and xylene in different microenvironments at the Mexico city metropolitan zone. Sci Total Environ 287:241–248

Park KH, Jo WK (2004) Personal volatile organic compounds (VOV) exposure of children attending elementary schools adjacent to industrial complex. Atmos Environ 38:1303–1312

Pearson RL, Wachtel H, Ebi KL (2000) Distance-weighted traffic density in proximity to a home is a risk factor for leukemia and other childhood cancers. J Air Wastes Manage 50:175–180

Raaschou-Nielsen O, Lohse C, Thomsen BL, Skov H, Olsen JH (1997) Ambient air levels and the exposure of children to benzene, toluene, and xylenes in Denmark. Environ Res 75:149–159

Serrano-Trespalacios PI, Ryan L, Spengler JD (2004) Ambient, indoor and personal exposure relationships of volatile organic compounds in Mexico city metropolitan area. J Expo Anal Env Epid 14:s118–s132

Sexton K, Adgate JL, Ramachandran G, Pratt GC, Mongin SJ, Stock TJ, Morandi MT (2004) Comparison of personal, indoor, and outdoor exposures to hazardous air pollutants in three urban communities. Environ Sci Technol 38:423–430

Son B, Breysse P, Yang W (2003) Volatile organic compounds concentration in residential indoor and outdoor and its personal exposure in Korea. Environ Int 29:79–85