Outdoor, Indoor, and Personal Exposure to VOCs in Children

John L. Adgate,[1] Timothy R. Church,[1] Andrew D. Ryan,[1] Gurumurthy Ramachandran,[1] Ann L. Fredrickson,[1] Thomas H. Stock,[2] Maria T. Morandi,[2] and Ken Sexton[3]

[1]Division of Environmental Health Sciences, School of Public Health, University of Minnesota, Minneapolis, Minnesota, USA; [2]University of Texas, Houston Health Science Center, School of Public Health, Houston, Texas, USA; [3]University of Texas, School of Public Health, Brownsville Regional Campus, Brownsville, Texas, USA

We measured volatile organic compound (VOC) exposures in multiple locations for a diverse population of children who attended two inner-city schools in Minneapolis, Minnesota. Fifteen common VOCs were measured at four locations: outdoors (O), indoors at school (S), indoors at home (H), and in personal samples (P). Concentrations of most VOCs followed the general pattern O ≈ S < P ≤ H across the measured microenvironments. The S and O environments had the smallest and H the largest influence on personal exposure to most compounds. A time-weighted model of P exposure using all measured microenvironments and time–activity data provided little additional explanatory power beyond that provided by using the H measurement alone. Although H and P concentrations of most VOCs measured in this study were similar to or lower than levels measured in recent personal monitoring studies of adults and children in the United States, *p*-dichlorobenzene was the notable exception to this pattern, with upper-bound exposures more than 100 times greater than those found in other studies of children. Median and upper-bound H and P exposures were well above health benchmarks for several compounds, so outdoor measurements likely underestimate long-term health risks from children's exposure to these compounds. *Key words:* air pollution, elementary school children, ethnicity, health risk, race, SHIELD study. *Environ Health Perspect* 112:1386–1392 (2004). doi:10.1289/ehp.7107 available via *http://dx.doi.org/* [Online 15 July 2004]

Although ambient levels of the major criteria pollutants have declined in the United States over the last 30 years, much less is known about exposure to many of the 189 hazardous air pollutants identified in the 1990 Clean Air Act Amendments (Clean Air Act Amendments 1990). Volatile organic compounds (VOCs) are an important class of outdoor air toxics because they are ubiquitous and associated with increased long-term health risks (Pratt et al. 2000; Woodruff et al. 1998). VOCs are also an indoor air quality issue because humans spend, on average, nearly 90% of their time indoors (Klepeis et al. 2001). VOCs in ambient air largely originate from mobile and industrial sources. The cumulative risk from exposure to multiple VOCs and other air pollutants is not known, and limited evidence suggests that the minority populations residing in inner-city neighborhoods have disproportionately higher exposures (Kinney et al. 2002; Metzger et al. 1995). There are relatively few data on VOC exposures in children or for minority populations in the United States (Adgate et al. 2004).

Past research has shown that VOCs are typically higher indoors than outdoors and that construction materials and building characteristics, such as the presence of an attached garage or air exchange rate, can influence levels or indoor:outdoor ratios (Levin 1989; Otson et al. 1994; Wallace 2001; Wallace et al. 1985). The contribution of indoor sources, such as consumer products and environmental tobacco smoke (ETS), is the largest source of variability in measured personal and indoor levels of many compounds (Sexton et al. 2004a; Wallace 2001). Compounds associated with consumer product use include *p*-dichlorobenzene (moth cakes, room air fresheners, toilet bowl deodorizers), chloroform (chlorinated water), and the fragrances α- and β-pinene and *d*-limonene (cleaning products, room fresheners) (Wallace 1991a, 1991b). Benzene and styrene have been shown to be elevated in homes with smokers, but these compounds also originate from traffic and are often higher in urban areas (Edwards et al. 2001).

Characterizing air pollution exposures in inner-city children is important for providing benchmarks for assessing environmental justice, estimating health risks, recommending interventions, and designing epidemiologic studies. We measured outdoor, indoor at school and home, and personal VOC concentrations for an ethnically and racially diverse sample of inner-city children in Minneapolis, Minnesota. These children were participants in the School Health Initiative: Environment, Learning, and Disease (SHIELD) study (Sexton et al. 2000, 2003), which selected participants at random with known probabilities from a defined sampling frame so inferences could be drawn about sociodemographic groups in two elementary schools. This analysis examines the distribution of exposures to common VOCs measured in the personal air and three primary microenvironments where these children spent time. We also examine how VOC exposures vary by sociodemographics, source/housing characteristics, and time–activity patterns and compare these results with health benchmarks and levels observed in recent VOC exposure studies in children and adults.

Materials and Methods

The SHIELD study was approved the University of Minnesota Research Subjects' Protection Program Institutional Review Board: Human Subjects Committee and examined children's exposures to a complex mixture of environmental agents, including VOCs and other chemical and biological agents. A detailed description of the SHIELD study design, eligibility criteria, sample selection, informed consent process, and response rates has been published (Sexton et al. 2000, 2003) and is briefly summarized here.

Children from two inner-city schools serving predominantly low-income households (> 90% qualified for free or reduced-price meals in the National School Lunch/Breakfast Program) in Minneapolis were recruited between November 1999 and January 2000. The three largest racial/ethnic groups that enrolled in SHIELD were African Americans, Hispanics, and Somalis, with a smaller number of Caucasians, Native Americans, Southeast Asians, and those declaring "other" or mixed-race ancestry. We used a stratified random sample to ensure an adequate number of subjects within the following defined subgroups of children: school (Lyndale, Whittier), grade (2nd, 3rd, 4th, 5th), language (English or non-English language spoken at home), and sex (female, male). This produced 32 distinct strata, with a target of five "index" children per stratum, for a target sample size of 80 children/school. A total of 153 index children were

Address correspondence to J.L. Adgate, University of Minnesota School of Public Health, Division of Environmental Health Sciences, Room 1260 Mayo, 420 Delaware St. SE, Minneapolis, MN 55455 USA. Telephone: (612) 624-2601. Fax: (612) 626-4837. E-mail: jadgate@umn.edu

We are especially grateful to the participant families and to K. Meyer, D. Heistad, S. Mullett, S. Poston, D. Schultz, O. Brooks-James, B. Cefalu, S. Bishop, L. Zeno, and other staff at the Minneapolis Public Schools for their help in making this study possible. Collaboration with the Minnesota Department of Health Indoor Air Program was invaluable to the success of the study.

This research was funded by U.S. Environmental Protection Agency STAR grants (R825813 and R826789) and a grant from the Legislative Commission on Minnesota Resources.

The authors declare they have no competing financial interests.

Received 22 March 2004; accepted 14 July 2004.