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ABSTRACT

The School Health Initiative: Environment, Learning, and Disease (SHIELD) study examined children's exposure to complex mixtures of environmental agents (i.e., volatile organic chemicals, environmental tobacco smoke, allergens, bioaerosols, metals, and pesticides). Environmental, personal, and biological data were collected on ethnically and linguistically diverse children in grades 2-5 from two Minneapolis, Minnesota, elementary schools. The enrollment rate for English-speaking, predominantly African American families was 42 percent, compared to 71 percent for non-English-speaking families (predominantly Somali and Hispanic). Most SHIELD households were low income, and 44 percent had no occupant with a high school degree or equivalent. These preliminary results indicated that there were ethnic/racial differences in exposure to environmental tobacco smoke in two economically disadvantaged neighborhoods. African American children tended to have the highest exposure, and Hispanic and Somali children had the lowest exposure. Both the baseline questionnaire and time-activity log did a reasonably good job of predicting urine total cotinine levels. Measured urine total cotinine levels were relatively good predictors of urinary NNAL+ NNAL-Gluc. Temperature, relative humidity, carbon dioxide, and carbon monoxide levels were comparable inside an older and newer elementary school. Differences were noted on several of the measures by race or language group. (SM)

School-Based Study of Complex Environmental Exposures and Related Health Effects in Children: Part A - Exposure

Final Report and Executive Summary

School of Public Health, University of Minnesota, Minneapolis

April 9, 2003

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FINAL REPORT AND EXECUTIVE SUMMARY

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Project Title: School-Based Study of Complex Environmental Exposures and Related Health Effects in Children: Part A – Exposure
Investigators: K. Sexton, J.L. Adgate, T.R. Church. G. Ramachandran, I.A. Greaves
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Summary

The School Health Initiative: Environment, Learning, and Disease (SHIELD) study examined children's exposure to complex mixtures of environmental agents (i.e., volatile organic chemicals, environmental tobacco smoke, allergens, bioaerosols, metals, pesticides). Details of this probability study, including design and monitoring methods, have been published previously (Sexton et al. 2000). Results of cotinine measurements (Hecht et al. 2001, Sexton et al. 2003a) and a summary of recruitment, retention, and compliance outcomes (Sexton et al. 2003b) have also been published. A manuscript that compares indoor air quality between the older Lyndale school and the newer Whittier school has been submitted for publication. Analysis of other exposure results (metals, volatile organic compounds, pesticides) is underway, and only preliminary data are presented here. An EPA-funded companion project incorporated a pilot epidemiologic study to examine links between measured exposures and effects on both respiratory health (e.g., spirometry and peak flow data) and learning outcomes (e.g., standardized test scores, measures of academic performance, attendance). These results will be the subject of a separate final report.

Study Population

The SHIELD study was designed to measure important environmental health variables for more than 550 children in grades 2 through 5 enrolled at two elementary schools, Lyndale and Whittier, in south Minneapolis. The Lyndale elementary school is located 8 blocks south of the Whittier school and similar numbers of children (269 at Lyndale, 289 at Whittier) were enrolled in grades 2 – 5 at the start of the 1999/2000 school year. The 558 children eligible for SHIELD comprise a diverse mix of ethnic and racial backgrounds: 356 (63.8%) black (including 114 Somali); 114 (20.4%) Hispanic; 37 (6.6%) white; 35 (6.3%) Asian; and 16 (2.9%) Native American. Just over half the children, 146 at Lyndale (54.3%) and 149 at Whittier (51.6%), live in households where English is the primary language. The rest of the children's families speak a variety of other languages, primarily Somali or Spanish.

Study Design

A stratified-random sampling designed was used to ensure adequate numbers within defined subgroups of children with known sampling probabilities. Strata were defined by school attended (Lyndale, Whittier), grade (2nd, 3rd, 4th, 5th), language category (English or Non-English spoken at home), and gender (female, male), which produced 32 distinct strata. The goal was to have a sample of five children within each stratum (5 X

32), which meant a target sample size of 80 from each school. The sampling strategy ensured that these 80 children (referred to as "index" children) were from 80 different families.

Recruitment for Year-1 occurred from November 1999 through January 2000, and re-enrollment for Year-2 took place from November 2000 through January 2001. Environmental, personal, and biological data were collected during two monitoring sessions in each school year. Numerous activities were undertaken before and during recruitment to inform and involve community members in the study (e.g., letters to key community groups, presentations at parent-teacher meetings and school open houses, distribution of brochures). In Year-1, blood and urine samples were collected in February-March 2000 and April-May 2000. In Year-2, blood and urine samples were collected in February-March 2001 and May 2001.

Results – Household Income and Education (from Sexton et al. 2003b)

Most SHIELD households were low-income, with 27% earning less than $9,999 per year, 30% between $10,000 and $19,999 per year, and 21% between $20,000 and $29,999 per year. Only 8% of households earned between $30,000 and $39,999 per year, and just 3% earned more than $50,000. There were some obvious ethnic/racial differences, with 61% of Somali households earning less than $9,999 (versus 16% African American, 17% Hispanic, 23% Other), and 19% of African Americans and 17% of "other" ethnic/racial groups earning more than $30,000 per year (versus 3% Somali and 0% Hispanic). To put these household incomes in perspective, the 2002 Health and Human Services poverty guidelines set the poverty level for a family of four at $18,100 per year (range from $8,860 for a single person to $30,420 for a family of eight).

With regards to education, 44% of participating households had no occupant with a high school degree or equivalent, while 32% had a high school graduate (or GED), and 23% had at least a college graduate or technical certificate holder. Again there were differences by ethnicity/race, with 76% of Somali and 91% of Hispanic households having no occupant with at least a high school degree (versus 4% African American and 33% Other), and 43% of African American households having an occupant with at least a college degree or technical certificate (versus 2% Hispanic, 12% Somali, 25% Other).

Results – Recruitment and Retention (from Sexton et al. 2003b)

In Year-1, a random sample of 311 "index" children was selected. Forty-one of these children had transferred out of the Lyndale and Whittier schools by the time recruiting ended. Of the remaining 270 eligible children, 153 index children were subsequently enrolled in Year-1. If the index child had siblings in grades 2–5, they were also asked to participate, and 51 siblings were enrolled in Year-1. The original 153 index children (plus their 51 siblings) were eligible for Year-2 provided that they were registered at a school within the MPS system. One hundred and seven index children along with 36 siblings were ultimately re-enrolled for Year-2. A child was considered to be enrolled (or re-enrolled) when the parent or guardian signed the written consent form, the child signed the written assent form, and the parent or guardian completed the baseline questionnaire.

The overall enrollment rate for Year-1 was 57%, with English-speaking families (42%) volunteering at a substantially lower rate than non-English-speaking families (71%). For Year-2, the overall re-enrollment rate was (79%) and the disparity between English-speaking (62%) and non-English-speaking (88%) families persisted. A summary of overall recruitment results for both years is provided in Table 1.

Results – Collection of Blood and Urine Samples (from Sexton et al. 2003b)

Rates of data capture for blood and urine samples are presented in Table 1. Statistically significant differences (Chi-Squared Statistic, $p<0.05$) were found between:

schools (children at Lyndale were consistently more likely to provide blood samples in both years, and urine samples in Year-1); grades (blood and urine samples in both years); gender (blood and urine samples in Year-2); and language (in Year-2, students from English-speaking homes were more likely to provide both samples of blood and urine, and at least one urine sample than children from non-English-speaking homes).

Ninety-seven index children agreed to provide blood and urine samples for both Year-1 and Year-2 of SHIELD. The maximum possible number of biological samples from each of these children was 4 blood and 4 urine samples (collected in the winter and spring of both years). We obtained all 4 blood samples from 77 children (84%), 3 or more from 91 children (93%), and 2 or more from 96 children (>99%). Results for urine collection were somewhat higher, with 93 children (91%) providing 4 samples, and 105 (99%) providing three or more samples.

Results – Collection of Personal VOC, Time-Activity, and Lung-Function Data (from Sexton et al. 2003b)

In Year-1, index children were asked to wear a small passive monitor (clip-on badge) for 48 consecutive hours (prior to the blood sample) to measure airborne VOC (volatile organic chemical) concentrations. Each child was also asked (Year-1 only), with the help of parents/guardians, to maintain a 48-hour diary (in the form of a simple questionnaire) of time spent in seven microenvironments (inside at home, school, other; outside at home, school, other; in transit). In the spring of both years, the school nurse at each school conducted lung spirometry for children enrolled in SHIELD. In addition, for Year-1 only, all students in the 4^{th} and 5^{th} grades at both schools (whether they were enrolled in SHIELD or not) were asked, as part of an in-class experiment, to participate in measurements (using small, hand-held flow measuring devices) of peak expiratory flow and forced expiratory volume (in one second).

A summary of data capture for personal VOC badges, time-activity diaries, and lung function tests is given in Table 1. Data capture rates were relatively high for personal VOC badges (83% provided both samples), personal time-activity diaries (67% provided both samples), and spirometry data (more than 90% of the children completed this testing each year). Complete peak flow data were obtained at progressively decreasing rates, starting in fall 1999 (91%), and continuing in the winter (76%) and spring (47%). Only 34% (weighted percentage) of the children provided valid peak flow samples for both the winter and spring 2000 monitoring sessions.

The primary reason that requested VOC badges and time activity diaries were not obtained from some children was because they had transferred to another school. The relatively low data capture rate for peak flow data is at least partially explained by the demanding nature of the testing, which required that children be present in class on mornings and afternoons of at least two of three testing days during the designated testing week, and successfully complete three valid FEV_1 (forced expiratory volume in 1 second) measurements in both the morning and afternoon.

Results – Exposure to Environmental Tobacco Smoke (from Sexton et al. 2003a)

As part of SHIELD, children's exposure to ETS (environmental tobacco smoke) was assessed using two relatively inexpensive metrics, baseline questionnaires (BQ) about caregiver smoking status/behavior and time-activity (T-A) logs reporting the time and place of ETS exposure, and two relatively expensive metrics, measurement of urinary total cotinine as an uptake marker of nicotine, and measurement of NNAL + NNAL-Gluc (NNAL = 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanol; NNAL-Gluc = 4-(methylnitrosamino)-1-(3-pyridyl)-1-(*O*-β-D-glucopyranuronosyl)butane) as an uptake marker of the tobacco-specific lung carcinogen NNK (4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone).

Geometric mean cotinine concentrations were <5 ng/ml for the entire cohort, as well as for each of the ethnic/racial groups, and no major seasonal differences were apparent. Geometric mean cotinine levels were substantially higher for African American children (3.4 ng/ml winter, 3.6 ng/ml spring) compared to children classified as "other" (2.2 ng/ml in winter, 1.4 ng/ml in spring). Mean cotinine values for "other" children were, in turn, substantially higher than for Hispanic (0.6 ng/ml in winter and spring) and Somali immigrant children (0.7 ng/ml in winter, 0.4 ng/ml in spring). This general pattern (African American > "Other" > Hispanic and Somali) was similar to that observed for the responses to smoking-related questions on the baseline questionnaire and information derived from the time-activity log.

Regression models were used to validate responses to smoking-related questions on the baseline questionnaire (BQ), information from the time-activity (T-A) log, or a combination of the two as predictors of urine cotinine concentrations. The estimates of proportion of explained variance (r^2) were adjusted for the number of covariates and compared for the models tested. Individually, both the BQ and T-A log predicted cotinine with reasonable reliability (adjusted $r^2 > 0.45$). The BQ was slightly better than the T-A log even though the BQ was administered several weeks prior to sample collection, while the T-A log was completed during the two days preceding sample collection. In combination, the BQ and T-A log were better yet. For example, the BQ plus the T-A log (winter and spring) explained 69% (adjusted r^2) of the variance in average (winter and spring) urine cotinine levels compared to 58% for the BQ alone and 66% for the T-A log alone.

Preliminary Results – Personal, Indoor, and Outdoor VOC Badges

Overall, data capture rates were relatively high for VOC badges, including personal and indoor residential. Initial findings indicate that, for 14 of the 15 compounds examined (all except carbon tetrachloride), VOC levels indoors and outdoors at schools were lower than those measured by personal and indoor-at-home badges. Our preliminary analyses suggest that, over the 2-day measurement period, personal VOC concentrations were similar to or lower than indoor-at-home VOC exposures. This suggests that the indoor-at-home environment may be the largest source of exposure to these compounds for the children in our study. Further statistical analyses will be undertaken to analyze the associations between time-activity patterns and concentrations in personal air, indoor residential environments, and indoors and outdoors at schools.

Preliminary Results – Biomarkers for VOCs, Metals, IgE

Preliminary analyses of biomarkers for VOCs, metals (Pb, Hg), and allergens (IgE) are summarized in Table 2 for SHIELD children. Results reveal that most children were exposed to relatively low levels of multiple pollutants, including VOCs and metals, although a few children in the upper tail of the distribution experienced higher exposures. The levels of IgE (indicating exposure to allergens) were relatively high for many children (compared to typical levels for white adults in Minnesota). Statistical analysis of these data is ongoing and results will be reported, as they become available, in future publications.

Results – Indoor Air Quality in Elementary Schools (from Ramachandran et al. 2003)

Four indoor air quality parameters - temperature, relative humidity, CO_2, and CO levels – were measured continuously at several locations in two inner-urban elementary schools in Minneapolis, Minnesota over three seasons. One of the schools is an older building built 35 years ago, while the other school is less than 2-years old and was built specifically to minimize indoor air quality problems. Findings indicate that there were no meaningful differences between the two schools for any of the four parameters that were measured. The levels of CO_2 measured at the two schools are considerably lower than those reported in the literature, and well within ASHRAE guidelines. However, roughly a third of the average school-day temperature and relative humidity measurements did not meet ASHRAE guidelines. The lack of any differences between an older and a newer school appears to indicate that even an older school can be operated to provide a well-ventilated environment and, conversely, even a new building constructed to minimize indoor air quality problems can fail to meet ASHRAE guidelines if not operated and maintained properly.

Summary and Conclusions

Recruitment, retention, and data capture rates for SHIELD were comparable to other children's studies, despite the complexity and comparatively invasive nature of the SHIELD protocols. The data indicate that a school-based, probability sampling strategy is a practical, affordable, and effective method for studying children's environmental health in poor minority neighborhoods. The primary advantages of a school-based design are numerous: (1) the process of identifying households with age-eligible children is direct, simple, and relatively inexpensive; (2) contact information (i.e., names, telephone numbers, addresses) and sociodemographic information (e.g., race/ethnicity of child, language spoken at home) is readily available, provided appropriate safeguards are in place to protect privacy; (3) the involvement of school personnel (e.g., recruitment letter from the principals, use of bilingual education assistants as recruiters) lends credibility to the study and increases the likelihood that children/families will volunteer to participate; (4) information available from the schools (e.g., race/ethnicity of child, language spoken at home, academic performance, standardized test scores) makes it easier to assess differences in responders and non-responders; and (5) the in-school collection of biological samples (blood and urine) and testing of lung function (spirometry and peak flow) is a convenient and effective way to monitor children's environmental health (Sexton et al. 2003b).

Notwithstanding these advantages, the enrollment rate for English-speaking, predominantly African American families was just 42%, compared to 71% for non-English-speaking families (predominantly Somali and Hispanic). Once enrolled, however, virtually all children/families participated fully in this relatively burdensome study, doing their best to comply with sometimes-demanding study protocols and willingly providing blood and urine samples. The primary reason that children/families dropped out of SHIELD was because they moved and/or transferred to another school. Although results from SHIELD are encouraging, findings also indicate that there is a continuing need to improve our understanding of cultural, economic, psychological, and social factors that encourage or discourage participation among this population (Sexton et al. 2003b).

There are two major findings from the ETS data. First, there were apparent ethnic/racial differences in children's exposure to ETS in two economically disadvantaged neighborhoods. Based on multiple exposure indicators (baseline questionnaires, time-activity logs, total urinary cotinine), a clear and consistent pattern emerged: African American children tended to have the highest exposure; children classified as "other" (white, Asian, Native American) tended to be intermediate; and Hispanic and Somali immigrant children typically had the lowest exposure. Second, both the BQ and T-A log did a reasonably good job of predicting urine total cotinine levels, and measured urine total cotinine levels were a comparatively good predictor of urinary NNAL + NNAL-Gluc, based on analysis of a relatively small number of samples. Our results point up the importance of considering ethnicity and race when conducting ETS exposure studies, demonstrate the value of measuring biomarkers of uptake for accurate assessment of children's exposure to ETS, and show the potential value of questionnaires and time-activity logs as screening tools or adjunct exposure metrics.

Continuous indoor air quality data revealed that temperature, relative humidity, carbon dioxide and carbon monoxide levels were comparable inside an older and a newer elementary school. In fact, there were no meaningful differences observed for the four parameters measured. The levels of carbon dioxide inside both schools were well below typical values reported in the literature, and were easily within ASHRAE guidelines. However, temperature and relative humidity were frequently outside ASHRAE recommended guidelines in both schools.

Future publications will build on and expand the knowledge gained so far. Our focus will continue to be on documenting and understanding children's exposure to multiple environmental agents. Once all the pesticides data become available we will begin to analyze results for children's exposure to persistent and non-persistent pesticides.

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Publications

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Ramachandran G, Church TR, Adgate JL, Jones D, Fischer G, Fredrickson AL, Sexton K. Indoor air quality measurements in older and newer elementary schools: Temperature, humidity, carbon dioxide, and carbon monoxide. Submitted for Publication, 2003.

Manuscripts in Preparation

Adgate JL, et al. Children's personal, indoor, and outdoor exposure to volatile organic chemicals.

Church TR, et al. Statistical relationships between multiple biomarkers of exposure and respiratory health for economically disadvantaged children.

Greaves IA, et al. Respiratory symptoms, lung function, atopy and asthma among poor inner city children from two elementary schools.

Ramachandran G, et al. Volatile organic compounds and bioaerosols inside two elementary schools.

Sexton K, et al. Concentrations of volatile organic compounds in the blood of elementary school children and associations with personal monitoring results.

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Relevant Web Sites – None

Table 1. Summary of Recruitment, Retention, and Monitoring Results from Years 1 and 2 of the SHIELD Study

Parameter		Year 1		Year 2	
Enrollment[a]	N	153/270		NA	
	raw rate	57%			
	weighted rate[d]	56%			
Re-enrollment[a]	N	NA		107/136	
	raw rate			79%	
	weighted rate			73%	
Retention[b]	N	130/153		101/107	
	raw rate	85%		94%	
	weighted rate	85%		95%	
Data capture		At Least One Sample	Both Samples	At Least One Sample	Both Samples
Blood	N	128/139	114/139	99/103	90/103
	raw rate	92%	82%	96%	87%
	weighted rate	92%	85%	97%	92%
Urine	N	143/153	131/153	105/107	100/107
	raw rate	93%	86%	98%	93%
	weighted rate	93%	87%	99%	97%
VOC Badge	N	127/140	115/140	NA	NA
	raw rate	91%	82%		
	weighted rate	91%	83%		
TA log	N	124/140	92/140	NA	NA
	raw rate	89%	66%		
	weighted rate	89%	67%		
Spirometry	N	137/153	NA	103/107	NA
	raw rate	90%		96%	
	weighted rate	91%		98%	
Peak Flow[c]	N	57/74	24/74	NA	NA
	raw rate	77%	32%		
	weighted rate	76%	34%		

NA = not applicable

VOC = volatile organic chemicals

TA = time-activity

[a]Number of children for whom consents and assents were obtained and a baseline questionnaire completed

[b]Number of children providing at least one blood or urine sample and completing the follow-up questionnaire

[c]Number of children providing valid peak flow data for the Winter and Spring monitoring sessions 2000

[d]The weighted rates are calculated using weighted counts that adjust for selection and response probabilities

Table 2. Summary of Preliminary Results for Biomarkers of VOCs, Metals, and Cotinine Measured in SHIELD Children.

	YEAR – 2000					YEAR – 2001				
Biomarker	**N**	**Geometric Mean**	**S.D.**	**Q25**	**Q75**	**N**	**Geometric Mean**	**S.D.**	**Q25**	**Q75**
VOCs (ng/ml in blood)										
1,1,1-trichloroethane	188	0.02	0.02	0.01	0.02	138	0.04	0.01	0.03	0.04
1,4-dichlorobenzene	188	0.22	22.83	0.06	0.91	140	0.27	5.83	0.06	1.4
benzene	189	0.05	0.02	0.04	0.06	132	0.12	0.07	0.09	0.16
carbon tetrachloride	187	0.004	0.003	0.004	0.004	108	0.01	0.02	0.01	0.01
ethylbenzene	179	0.03	0.02	0.02	0.04	143	0.04	0.01	0.03	0.05
m/p-xylene	189	0.13	0.05	0.11	0.15	143	0.29	0.12	0.24	0.37
o-xylene	189	0.03	0.02	0.02	0.04	143	0.05	0.03	0.04	0.09
styrene	185	0.12	0.29	0.07	0.30	143	0.10	0.03	0.09	0.11
tetrachloroethylene	189	0.03	0.10	0.02	0.04	141	0.04	0.16	0.03	0.04
toluene	185	0.10	0.09	0.08	0.13	141	0.15	0.09	0.11	0.20
trichloroethene	187	0.006	0.004	0.006	0.006	143	0.010	0.004	0.009	0.009
Metals (µg/L in blood)										
Mercury	190	0.36	0.83	0.15	1.00	143	0.25	0.61	0.10	0.80
Lead	190	2.34	1.59	1.60	3.50	143	1.84	1.63	1.10	2.80
Total IgE (IU/ml in blood)	158	74	426	28	214	32	48	223	17	109
Mercury (µg/L in urine)	NA	NA	NA	NA	NA	157	0.50	0.71	0.28	0.79
Cotinine (ng/ml in urine)	204	1.34	15.61	0.20	7.46	NA	NA	NA	NA	NA