ehp ENVIRONMENTAL HEALTH PERSPECTIVES

ehponline.org

Prenatal Exposure to Organophosphates, Paraoxonase 1, and Cognitive Development in Childhood

Stephanie M. Engel, James Wetmur, Jia Chen, Chenbo Zhu, Dana Boyd Barr, Richard L. Canfield, and Mary S. Wolff

doi: 10.1289/ehp.1003183 (available at http://dx.doi.org/)
Online 21 April 2011

NIEHS
National Institute of Environmental Health Sciences

National Institutes of Health
U.S. Department of Health and Human Services

Prenatal Exposure to Organophosphates, Paraoxonase 1, and Cognitive Development in Childhood

Stephanie M Engel[1], James Wetmur[2], Jia Chen[1], Chenbo Zhu[1], Dana Boyd Barr[3], Richard L. Canfield[4], Mary S Wolff[1]

[1] Department of Preventive Medicine, Mount Sinai School of Medicine, New York, NY

[2] Departments of Microbiology and Human Genetics, Mount Sinai School of Medicine, New York, NY

[3] School of Public Health, Emory University, Atlanta, Georgia, USA

[4] Division of Nutritional Sciences, College of Human Ecology, Cornell University, Ithaca, New York, USA

Corresponding Author:

Dr. Stephanie Engel

Address: Department of Epidemiology

Gillings School of Global Public Health

University of North Carolina, Chapel Hill

2104C McGavran-Greenberg, Box 7435

Chapel Hill, NC 27599-7435, USA

Phone number: 919-966-7435

Email: Stephanie.Engel@unc.edu

Running Title: Prenatal Pesticides and Cognitive Development

Key words: environmental exposures, IQ, mental development, Organophosphates, pesticides

Article Descriptors: Child behavior, phthalate exposure

Funding and Disclaimer: This research was supported by NIEHS/EPA Children's Center grants ES09584 and R827039, The New York Community Trust, and ATSDR/CDC/ATPM. The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the CDC.

Acknowledgements: The authors gratefully acknowledge the tremendous contributions of Dr. Gertrud Berkowitz in developing the NYCEH cohort. The authors would also like to thank Martha Lievano, Stefanie Meisel, Karen Ireland, Zhisong Liu and Kelly Nichols for their valuable assistance.

Conflict of interest: The authors have no conflicts of interest to declare.

Abbreviations:

BSID-II	Bayley Scales of Infant Development, version II
CI	Confidence Interval
DDE	1,1'-dichloro-2,2'-bis(4-chlorophenyl)ethylene
ΣDAP	sum of dialkylphosphate metabolites
ΣDEP	sum of diethylphosphate metabolites
ΣDMP	sum of dimethylphosphate metabolites
FSIQ	full-scale IQ
HOME	Home Observation for Measurement of the Environment
MDI	Mental Development Index
OP	organophosphate
PCBs	polychlorinated biphenyls
PDI	Psychomotor Development Index
PON1	paraoxonase 1
SD	Standard deviation
WISC-IV	Wechsler Intelligence Scale for Children - Fourth Edition
WPPSI-III	Wechsler Preschool and Primary Scale of Intelligence - Third Edition

ABSTRACT

Background: Prenatal exposure to organophosphate pesticides has been shown to negatively impact child neurobehavioral development. Paraoxonase 1 (PON1) is a key enzyme in the metabolism of organophosphates.

Objective: To examine the relationship between biomarkers of organophosphate exposure, PON1, and cognitive development at ages 12 and 24 months, and 6 to 9 years.

Methods: The Mount Sinai Children's Environmental Health Study enrolled a multiethnic prenatal population in New York City between 1998 and 2002 (n= 404). Third trimester maternal urines were collected and analyzed for organophosphate metabolites (n = 360). Prenatal maternal blood was analyzed for *PON1* activity and genotype. Children returned for neurodevelopment assessments at ages 12 months (n = 200), 24 months (n = 276), 6 to 9 (n = 169) years.

Results: Prenatal total dialkylphosphate metabolite level was associated with a decrement in mental development at 12 months among blacks and Hispanics. These associations appeared to be enhanced among children of mothers who carried the *PON1* Q192R QQ genotype, which imparts slow catalytic activity for chlorpyrifos oxon. In later childhood, increasing prenatal total dialkyl- and dimethylphosphate metabolites were associated with decrements in perceptual reasoning in the maternal *PON1* Q192R QQ genotype, with a monotonic trend consistent with greater decrements with increasing prenatal exposure.

Conclusion: Our findings suggest that prenatal exposure to organophosphates negatively impacts cognitive development, particularly perceptual reasoning, with evidence of effects beginning at 12 months and continuing through early childhood. PON1 may be an important susceptibility factor for these deleterious effects.

Background

Prior to 2001, residential exposure to organophosphate pesticides, including chlorpyrifos and diazinon, was common, even in an urban setting. Insecticides are used in multi-unit, inner city dwellings to control insect and rodent infestations within apartments, in common spaces, and around building exteriors. Despite the voluntary cancellation of residential use registrations of chlorpyrifos and diazinon in 2001 and 2004 respectively, between June 2005 and March 2006, 78% of randomly selected nationally representative US homes had measurable levels of chlorpyrifos, and 35% had measurable levels of diazinon, suggesting ongoing residential exposure (Stout et al. 2009). Additionally, exposure to organophosphate pesticides or their residues may occur via consumption of conventionally grown fruits and vegetables (Lu et al. 2008).

Neurodevelopmental consequences of human exposure to organophosphate pesticides have been demonstrated in urban (Bouchard et al. 2010; Engel et al. 2007; Rauh et al. 2006), rural (Eskenazi et al. 2010; Eskenazi et al. 2007; Young et al. 2005), and occupational settings (Handal et al. 2008; Roldan-Tapia et al. 2006), some of which specifically involve prenatal exposure (Engel et al. 2007; Eskenazi et al. 2010; Eskenazi et al. 2007; Marks et al. 2010; Rauh et al. 2006; Young et al. 2005). We have previously reported that prenatal pesticide exposure was associated with smaller head circumference (Berkowitz et al. 2004), and more abnormal primitive reflexes (Engel et al. 2007), particularly among children of mothers with low paraoxonase 1 (PON1) activity. PON1 is a key enzyme in the metabolism of organophosphate pesticides (Costa et al. 1999), and has been shown to be a biomarker of susceptibility to the toxic effects of organophophate pesticides, both in animals (Costa et al. 2003), and in humans (Engel et al. 2007; Eskenazi et al. 2010; Lee et al. 2003; Nielsen et al. 2010).

Objective

We undertook an investigation of the impact of prenatal organophosphate metabolite biomarker levels in relation to cognitive development at multiple times in childhood, while considering the modifying influence of maternal and child *PON1* genotype and enzymatic activity.

Methods

The Mount Sinai Children's Environmental Health Cohort study is a prospective multiethnic cohort that enrolled primiparous women who presented for prenatal care with singleton pregnancies at the Mount Sinai prenatal clinic and two private practices, and were subsequently delivered at Mount Sinai Hospital between May 1998 and July 2001. The target population was healthy, first born infants with no underlying health conditions that might independently result in serious neurodevelopmental impairment. Therefore, women were considered eligible if they were primiparous with singleton pregnancies, had no underlying health conditions that might predispose them to have serious complications of pregnancy that might result in an at-risk infant, and ultimately delivered infants that were neither extremely preterm nor very low birth weight. (Berkowitz et al. 2003; Berkowitz et al. 2004) Mother-infant pairs were recruited early in pregnancy (n = 479). In brief, subsequent to delivery, 75 women were excluded because of medical complications, very premature births (delivery before 32 completed weeks or less than 1500 grams), delivery of an infant with a birth defect, inability to collect biologic specimens before birth, change of hospital or residence outside New York City, or refusal to continue to participate, leaving 404 women-infant pairs in the final cohort (Berkowitz et al. 2004).

We administered a questionnaire to participants during their third trimester of pregnancy to obtain information on environmental exposures, sociodemographic characteristics, obstetrical and medical history, and lifestyle factors. Women self-identified as white, white Hispanic, black, black Hispanic, or other. For the purpose of this analysis, white Hispanic and black Hispanics were jointly considered Hispanic. Maternal blood and urine samples were also obtained during a routine clinical visit, generally between 26 and 28 weeks of gestation. Delivery characteristics and birth outcomes, including birth weight, length, head circumference, gestational age and infant gender, were obtained from a computerized perinatal database within the Department of Obstetrics, Gynecology and Reproductive Science at Mount Sinai Hospital.

The Bayley Scales of Infant Development (version II, BSID-II) was administered at the Mount Sinai Hospital at approximately 12 (n=200) and 24 months (n=276). The BSID-II provides age-standardized

norms of mental (MDI) and psychomotor (PDI) development. The MDI rates the child's cognitive ability in a number of areas, including memory, habituation, problem solving, early number concepts, generalization, classification, vocalizations, language and social skills. The PDI rates the child's fine and gross motor coordination. Scales are age-standardized to mean = 100, SD = 15 (Bayley 1993). Interviews and examinations were conducted in English or Spanish as required. Children were invited to return for Wechsler psychometric intelligence tests between the ages of 6 and 9 years. Children that returned before 7 years of age were administered the Wechsler Preschool and Primary Scale of Intelligence - Third Edition (WPPSI-III). The WPPSI-III was administered in English or Spanish by one of 4 examiners. Block Design, Information, Matrix Reasoning, Vocabulary, Picture Concepts, Symbol Search, Word Reasoning, and Coding subtests were completed. Composite Verbal, Performance, Processing Speed, and Full-Scale IQ scores were derived using age-standardized WPPSI-III norms. Children who returned between the ages of 7 and 9 years were administered the Wechsler Intelligence Scale for Children - Fourth Edition (WISC-IV) by one of 4 examiners. Children provided witnessed assent prior to the start of the assessment. Block Design, Similarities, Digit Span, Picture Concepts, Coding, Vocabulary, Letter-Number Sequence, Matrix Reasoning, Comprehension and Symbol Search subtests were completed. Composite Verbal, Perceptual Reasoning, Working Memory, Processing Speed, and Full-Scale IQ scores were derived using age-standardized WISC-IV norms. Both the WPPSI-III and the WISC-IV were administered in a private room without the parent present. Mothers provided informed consent and children aged 7 and older provided verbal and witnessed assent. This study was approved by the Institutional Review Board of Mount Sinai School of Medicine.

Maternal urine samples were analyzed by the Centers for Disease Control and Prevention for six dialkylphosphate metabolites in two batches. Laboratory and quality control methods have been reported previously (Barr et al. 2005; Bravo et al. 2004; Wolff et al. 2005). In some cases, individual dialkylphosphate metabolite levels were missing due to analytic interference. In these cases, missing dialkylphosphate metabolite levels were imputed using regression analysis to predict the missing metabolite on the basis of the other non-missing metabolites measured for that woman within the group of correlated metabolites, as has been previously described (Engel et al. 2007). Samples below the LOD were defined as LOD/$\sqrt{2}$. Diethyl- and dimethyl-phosphate metabolites were summed (as μm/L) to obtain

diethylphosphate (ΣDEP) and dimethylphosphate (ΣDMP) metabolites, respectively, and total dialkylphosphate (ΣDAP) levels. Very dilute samples of urine with < 20 µg/dL creatinine (n = 26) were excluded from organophosphate metabolite analyses, in accordance with methods that have previously been applied for spot urine biomarker measures (Carrieri et al. 2001; Engel et al. 2007; Eskenazi et al. 2004; Wolff et al. 2007). Overall, approximately 97%, 89%, and 90% of the cohort had detectable levels of ΣDAP, ΣDEP, and ΣDMP metabolites respectively (Engel et al. 2007). A random subset of maternal peripheral blood samples from the entire cohort (n = 194), distributed roughly equally by maternal race/ethnicity (66 blacks, 64 Hispanics, 64 whites, the number being dictated by budgetary considerations), was analyzed for polychlorinated biphenyls (PCBs) and 1,1'-dichloro-2,2'-bis(4-chlorophenyl)ethylene (DDE). PCBs were defined as the sum of congeners 118, 153, 138, and 180 (Wolff et al. 2005). Total lipids (g/liter) were calculated by using cholesterol and triglycerides (Phillips et al. 1989) determined on the 174 plasma samples with sufficient volume. Distributions of biomarker levels have been previously reported (Engel et al. 2007; Wolff et al. 2007).

Plasma was separated from prenatal maternal peripheral blood and cord blood at delivery, and was used to measure PON1 activity by phenylacetate hydrolysis (Chen et al. 2005). Using maternal and child DNA, *PON1* polymorphisms were also measured using clamp-dependent and linking emulsion allele-specific PCR (Chen et al. 2005). We examined interactions between prenatal organophosphate exposure (dichotomized as above and below the median exposure) and tertiles of PON1 activity in maternal prenatal peripheral blood and child cord blood. We also examined interactions between prenatal organophosphate exposure and the maternal or child *PON1* Q192R, -108C>T, and L55M polymorphisms. We closely examined interactions if the type 3 F-test for the product-term in Proc GLM (either the class variable representing biomarker tertiles * dichotomized genotypes or race/ethnicity, or the linear term for log10 organophosphate metabolites * dichotomized genotypes or race/ethnicity) was $p < 0.20$. The *PON1* Q192R polymorphism in particular has been shown to have a strong functional consequence on the relative rate of hydrolysis of certain organophophate substrates (Li et al. 2000), and has been shown to affect the catalytic efficiency for chlorpyrifos but not diazinon (Richter et al. 2009).

Data were analyzed using the SAS system version 9.1 (Cary, NC). Generalized linear models were used to analyze the relationship between biomarker levels and the Mental and Psychomotor Development Indices (MDI and PDI respectively). In total, 200 children were administered the BSID-II at approximately 12-months of age (mean 13.1 ± SD=1.6 months). Children were excluded from analyses if their refusal to do a large proportion of the items on the exam influenced their overall score (12-month MDI n = 1). Two children were excluded from the 12-month analysis because their parent reported a diagnosis of pervasive developmental disorder. We also excluded observations when urine creatinine was < 20 µg/dL in maternal urine sample (n = 20). Of the remaining 177 eligible children who completed 12-month exams, 174 had organophosphate metabolites measured in prenatal urine.

At the 24-month BSID-II (mean 27.4 ± SD=4.5 months), 276 children completed the exam. Two were excluded from the 24-month analysis because the parent reported a diagnosis of pervasive developmental disorder. Samples of urine < 20 µg/dL creatinine (n = 23) were also excluded. Of the remaining 251 eligible observations, 247 had organophosphate metabolites measured in prenatal urine. We could not compute the MDI scores for ten additional children because their refusals were too extensive to accurately calculate scores; however, they were included in the PDI analyses because their scores were valid..

In order to maximize the sample size of our models, we conducted analyses that combined the full-scale IQ (FSIQ), perceptual reasoning, verbal comprehension, and processing speed composite scores from children who came for at least one of the Wechsler psychometric intelligence exams—in the text & tables we refer to as the “combined populations” (n = 169). For these analyses, we preferentially selected the WISC-IV composite scores, and substituted the WPPSI-III composite scores if the child did not return for the later exam. We included an indicator variable to account for whether the scores derived from a WISC-IV or WPPSI-III exam. The convergent validity between the WISC-IV and WPPSI-III has been previously reported. Specifically, in psychometric analyses, the correlation between WPPSI-III and WISC-IV FSIQ scores was 0.89, WPPSI-III Verbal IQ versus WISC-IV Verbal Comprehension = 0.83, WPPSI-III Performance IQ versus WISC-IV Perceptual Reasoning = 0.79 (Flanagan and Kaufman 2004). In our

study, among children who returned for both exams (n = 103), the correlations between the composite scores on the WPPSI-III and WISC-IV were likewise very strong: FSIQ = 0.83, Verbal IQ/Verbal Comprehension = 0.84, and Performance IQ/Perceptual Reasoning = 0.78. For all models, covariates were retained if their exclusion caused more than a 10% change in the beta coefficient of the full model, or if they improved the precision of the main effect estimate. The following covariates were considered as potential confounders or effect modifiers: maternal age, race/ethnicity, marital status, education, breastfeeding, child sex, alcohol, smoking, or drug use during pregnancy, maternal IQ (measured by the Peabody Picture Vocabulary test), Home Observation for Measurement of the Environment (HOME) score, season of urine collection, maternal *PON1* activity or genotype, language spoken in the home, exact age at testing. Gestational age at delivery and birthweight were not evaluated for confounding because they are potentially causal intermediates (Moreno-Banda et al. 2009; Whyatt et al. 2004; Wolff et al. 2007). All models were adjusted for examiner and urinary creatinine.

Results

The Mount Sinai Children's Environmental Health Center enrolled a multiethnic inner city cohort, the majority of whom were black or Hispanic women (approximately 80%) (Table 1). Most of the cohort was less than 25 years of age at enrollment. However, in some follow-up years, those who returned for follow-up assessments tended to be older women, with a disproportionately low fraction of women in the youngest category (less than 20 years at enrollment) being unreachable by any of our contact methods. Similar trends were found for education. Those returning for follow up did not differ substantially from the originally enrolled cohort with respect to racial/ethnic composition. Importantly, there were also no meaningful differences with respect to breastfeeding behaviors or alcohol use during pregnancy. In general, mothers who returned for follow-up assessments tended to have been older at enrollment and to have achieved a higher level of education. Allele frequencies for *PON1* polymorphisms vary by race, as has been previously reported for our population (Chen et al. 2003). In the population of subjects included in this analysis, the frequency of the A allele (resulting in Q amino acid) is 74% among whites, 36% among blacks, and 55% among Hispanics. The frequency of the -108T allele, and 55L alleles are also

differential by race. A detailed description of allele frequencies and metabolite concentrations according to race can be found in Supplemental Material, Table 1.

At the 12-month BSID-II exam, the estimated effect of organophosphate metabolites on the MDI was strongly heterogeneous by race/ethnicity for the ΣDAP and ΣDMP metabolites (Table 2. Among nonwhites, increasing ΣDAP and ΣDMP tertiles of exposure were associated with a decrease in the MDI (log10 ΣDAP Beta = -3.29, 95% CI -5.88, -0.70). However, among whites, the reverse pattern emerged, with higher exposure associating with better MDI scores (log10 ΣDAP Beta = 4.77, 95% CI 0.69, 8.86). Similar trends in the effect estimates were found when we stratified by housing type (public versus private) rather than race/ethnicity. There was no heterogeneity in ΣDEP effect estimates according to race/ethnicity; and overall, ΣDEP metabolites were not associated with the 12-month BSID-II MDI. There was no relationship between organophosphate metabolites and the PDI at 12-months overall, and no interaction with race/ethnicity for any of the metabolite groups (Table 2). At the 24-month BSID-II, effect estimates were not heterogeneous by race/ethnicity (data not shown). Consistent with the 12-month assessment, prenatal maternal ΣDAP metabolite level was inversely associated with the 24-month MDI (B = -2.08, 95% CI -4.60, 0.44) in multivariate adjusted models, although the effect estimates were attenuated relative to the 12-month estimates and measured with comparable precision (see Supplemental Material, Table 2). The metabolites were not associated with 24-month PDI.

Because of the strong interaction between race/ethnicity and OP metabolites on the BSID-II MDI at 12-months, we examined the interaction between the *PON1* polymorphisms and ΣDAP and ΣDMP metabolites within strata of race/ethnicity; however, the white population was too small to further subdivide by genotype. Therefore we restricted this analysis to only the black or Hispanic population. Among blacks and Hispanics, the effects of ΣDAP, ΣDEP and ΣDMP were strongly differential according to *PON* Q192R genotype at 12-months, although not 24-months. At 12-months, children of mothers with the slow catalytic activity, *PON1* 192QQ genotype experienced an approximate 4 point decline on the MDI with each log10 unit increase in ΣDAP and ΣDMP biomarker level, with essentially no effect among children of mothers with the QR/RR genotype. Although in some instances the point estimate among the

QR/RR group were quite elevated in a positive direction, they were always estimated with greater imprecision, despite the fact that this was the larger strata (Table 3). A similar pattern was found for the ΣDEP-*PON1* Q192R interaction, although the differences between genotypes were less pronounced. Results were consistent when we stratified by black and Hispanic ancestry (see Supplemental Material, Table 3), although the sample size was quite small. There was no interaction between the *PON1* Q192R polymorphism and OP metabolite level on the MDI at 24-months. There were also no interactions ($p \geq 0.20$) between organophosphate metabolites and the L55M or -108C>T polymorphisms, nor with enzyme activity, on neurodevelopment at any age. Results were similar when we estimated associations according to the child's *PON1* Q192R genotype instead of the mother's genotype, but child genotype was only available for 57% of the population because cord blood was only collected on a subset. Therefore, we report only the maternal gene-OP interactions.

Increasing total DEP metabolite levels were associated with slight decrements in full scale IQ (log10 Beta = -2.89, 95% CI -6.15, 0.36) and perceptual reasoning (log10 Beta = -3.51, 95% CI -7.31, 0.30) on the combined psychometric exams, and also with Working Memory (log10 Beta = -3.48, 95% CI -7.29, 0.34) on the 7-9 year WISC-IV examination (Table 4), although the estimated effects were relatively modest and imprecise. These associations were not heterogeneous by race/ethnicity. However, for the combined population, there was again effect heterogeneity according to the *PON1* Q192R polymorphism for the associations between ΣDAP and ΣDMP biomarkers and perceptual reasoning domain., Children of mothers with the slow catalytic activity genotype (QQ) experienced a substantial decrement in the overall perceptual reasoning score with each log10 increment increase in exposure, while. there was no effect of ΣDAP and ΣDMP biomarkers on the perceptual reasoning score of children with mothers who carried the QR/RR genotypes (Table 5). Comparing biomarker tertiles according to genotype, increasing tertiles of ΣDAP, ΣDEP and ΣDMP among the children of mothers with the *PON1* 192QQ genotype were generally associated with monotonically declining LSMEANS in FSIQ and perceptual reasoning, while there was no consistent pattern in the QR/RR group (Figure 1). For perceptual reasoning, the first versus third tertile contrasts for ΣDAP and ΣDMP were statistically significant ($p < 0.05$).

Maternal third trimester blood PCB concentration was inversely associated with mental development at 12 months (log_e beta = -7.18, 95% CI -14.47, 0.11) but not at 24 months (log_e beta = 1.60, 95% CI -6.57, 9.77), and was not associated with IQ (see Supplemental Material, Table 4). However, although the effect estimates for PCBs were sometimes quite large, they were also measured with extreme imprecision, as indicated by the very large confidence intervals. Maternal third trimester blood DDE was not associated with any of the outcome measures.

Discussion

We report an association between prenatal increasing ΣDAP and ΣDMP urinary metabolite concentrations and poorer scores on the BSID-II MDI at 12-months among blacks and Hispanics. These associations were modified by maternal *PON1* Q192R genotype, such that negative effects appeared to be limited to children of mothers with the QQ genotype. Heterogeneity according to maternal race/ethnicity may indicate differences in exposure sources rather than any underlying susceptibility. As previously described, overall, 46.4% of our mothers reported that pesticides were applied in their home either by themselves or by a family member during their pregnancy (Berkowitz et al. 2003). However, there was a profound racial disparity in this behavior (Berkowitz et al. 2003). Among the women who returned for the 12-month BSID-II exam, 70.5% of the blacks and Hispanics reported buying pesticides, applying pesticides, or fumigating their house during their pregnancy, compared with only 31.6% of the whites, and yet we did not detect significant differences in their exposure distributions (Supplemental Material, Table 1). In our population, race/ethnicity was strongly associated with whether a subject lived in public or private housing. And indeed, similar trends in the effect estimates were found when we stratified by housing type (public versus private) rather than race/ethnicity, although the magnitude of the interaction was not as strong. This indicates that whites, or people living in private or owner-occupied housing, may have experienced a different source of exposure to pesticides or their metabolites that contributed substantially to their urinary concentrations; one possibility is that pesticide residues from fresh fruit and vegetable consumption account for a large fraction of the urinary metabolite levels among whites. Unfortunately this presents serious complications for exposure reconstruction using urinary metabolites. A recent examination of dialkylphosphate residues on fruits and vegetables found that over

half of the samples tested contained more pre-formed DAP residues than parent organophosphate pesticides (Zhang et al. 2008). These DAP residues were produced by abiotic hydrolysis, photolysis or plant metabolism (Zhang et al. 2008). Direct intake of the metabolite (i.e. pesticide residue) without the active oxon, rather than the parent pesticide, does not inhibit cholinesterase activity. Thus, for subjects for whom the primary source of pesticide exposure is fresh fruit and vegetable consumption, use of urinary metabolite concentrations as an indication of parent compound exposure may result in significant misclassification of exposure.

Between the ages of 6 and 9 years, prenatal ΣDEP urinary metabolite concentrations were associated with slight decrements in FSIQ, Perceptual Reasoning, and Working Memory. Furthermore, among children of QQ mothers, ΣDAP and ΣDMP urinary metabolite concentrations were associated with poorer scores on Perceptual Reasoning and FSIQ in a monotonically decreasing manner. In both cases, we observed stronger Q192R-interactions for ΣDAP and ΣDMP urinary metabolites, rather than ΣDEP metabolites. The reasons for this are unclear. *PON1* Q192R exhibits substrate specificity (Richter et al. 2009), but our strongest interactions were for dimethylphosphates, not diethylphosphates (into which chlorpyrifos and diazinon both metabolize). An alternative explanation is that our dimethylphosphate metabolite concentrations were simply higher (Engel et al. 2007), indicating more available substrate. Unfortunately the relevant parent compounds cannot be deduced on the basis of non-specific urinary DAPs; however, one well publicized source of DMP exposure during the period of enrollment was malathion spraying for West Nile carrying mosquitos (Nash et al. 2001; O'Sullivan et al. 2005). Interestingly, *PON1* status may indirectly influence methyl organophosphate metabolism when multiple organophosphate exposures are involved (Jansen et al. 2009).

The estimated effects we report for the BSID-II MDI are in line with what has recently been reported in the CHAMACOS study, a similarly designed prospective birth cohort that was enrolled in an agricultural community in the Salinas Valley of California (Eskenazi et al. 2010). Eskenazi et al. report evidence of negative effects of ΣDAPs on the MDI, but not the PDI, and particularly among children with the QQ genotype, although there did not appear to be strong effect heterogeneity in the DAP-MDI relationship

according to *PON* genotype.. Although we report interactions with maternal *PON1* Q192R genotype, very similar interactions and effect estimates were found for child genotype in our cohort (data not shown). In no cases was effect heterogeneity detected according to w PON1 enzyme activity. This may be because genotype is a more stable, long-term predictor of metabolism potential. Reconciling estimated effects across studies can be complicated when only non-specific urinary metabolites are measured because these metabolites can derive from multiple parent compounds (2005) that may vary in the degree to with they interact with the Q192R genotype and influence neurodevelopment.

Ours was a multi-ethnic study population recruited at an inner city tertiary care hospital that serves a lower income minority population. As such, attrition resulting from the challenges of maintaining contact with this population may have impacted our study findings. Misclassification of parent compound exposure according to exposure route is another significant limitation of our study and other studies relying on urinary DAP biomarkers, and may explain the heterogeneity in effects observed according to race/ethnicity in our population. It may further complicate the comparison of exposure effects across studies where there exists heterogeneity in exposure sources. Additionally, we measured DAP biomarkers at one time during pregnancy, approximately the early third trimester. Although we accounted for seasonal variation in exposure levels in our model, other time-related variability may result in additional misclassification of exposure.

Finally, residual confounding by unmeasured covariates, including postnatal exposure, should be considered when evaluating our results. It should be noted that our study enrollment and evaluation periods overlapped with important regulatory changes in residential use of chlorpyrifos and diazinon, which occurred approximately midway through our study. Therefore, childhood exposure to these compounds may vary substantially pre versus post-ban, although we did not observe any significant interaction with study year (data not shown). However, these changes may explain the inconsistency between our 12 and 24-month BSID-II results. The 0-12-month exposure window may include less hand-to-mouth childhood exposure (from crawling exposure to house dust, and/or fresh fruit and vegetable consumption) than in the 12-24 month window; thus, more childhood exposure in the 12-24 month

window may modify the effect of prenatal exposure. Nonetheless, it is likely, overall, that childhood exposure to chlorpyrifos and diazinon was lower post-ban (Williams et al. 2008).

In conclusion, we found that prenatal maternal urinary dialkylphosphate metabolite concentrations were negatively associated with aspects of neurodevelopment at 12 and 24 months, and also at 6 to 9 years of age in an urban, inner city population. The evidence was strongest among the children of mothers with the *PON1* 192QQ genotype, which was present in approximately 30% of our population overall, although that varies according to racial ancestry. This important potential source of effect heterogeneity should be considered in future studies of organophosphate exposure.

References

[Anonymous]. 2005. Centers for Disease Control and Prevention. Third National Report on Human Exposure to Environmental Chemicals. Atlanta (GA).

Barr DB, Allen R, Olsson AO, Bravo R, Caltabiano LM, Montesano A, et al. 2005. Concentrations of selective metabolites of organophosphorus pesticides in the United States population. Environ Res 99(3):314-326.

Bayley N. 1993. Bayley Scales of Infant Development, Second Edition. San Antonio: Harcourt Brace & Company.

Berkowitz GS, Obel J, Deych E, Lapinski R, Godbold J, Liu Z, et al. 2003. Exposure to indoor pesticides during pregnancy in a multiethnic, urban cohort. Environ Health Perspect 111(1):79-84.

Berkowitz GS, Wetmur JG, Birman-Deych E, Obel J, Lapinski RH, Godbold JH, et al. 2004. In utero pesticide exposure, maternal paraoxonase activity, and head circumference. Environ Health Perspect 112(3):388-391.

Bouchard MF, Bellinger DC, Wright RO, Weisskopf MG. 2010. Attention-deficit/hyperactivity disorder and urinary metabolites of organophosphate pesticides. Pediatrics 125(6):e1270-1277.

Bravo R, Caltabiano LM, Weerasekera G, Whitehead RD, Fernandez C, Needham LL, et al. 2004. Measurement of dialkyl phosphate metabolites of organophosphorus pesticides in human urine using lyophilization with gas chromatography-tandem mass spectrometry and isotope dilution quantification. J Expo Anal Environ Epidemiol 14(3):249-259.

Carrieri M, Trevisan A, Bartolucci GB. 2001. Adjustment to concentration-dilution of spot urine samples: correlation between specific gravity and creatinine. Int Arch Occup Environ Health 74(1):63-67.

Chen J, Chan W, Wallenstein S, Berkowitz G, Wetmur JG. 2005. Haplotype-phenotype relationships of paraoxonase-1. Cancer Epidemiol Biomarkers Prev 14(3):731-734.

Chen J, Kumar M, Chan W, Berkowitz G, Wetmur JG. 2003. Increased influence of genetic variation on PON1 activity in neonates. Environ Health Perspect 111(11):1403-1409.

Costa LG, Li WF, Richter RJ, Shih DM, Lusis A, Furlong CE. 1999. The role of paraoxonase (PON1) in the detoxication of organophosphates and its human polymorphism. Chem Biol Interact 119-120:429-438.

Costa LG, Richter RJ, Li WF, Cole T, Guizzetti M, Furlong CE. 2003. Paraoxonase (PON 1) as a biomarker of susceptibility for organophosphate toxicity. Biomarkers 8(1):1-12.

Engel SM, Berkowitz GS, Barr DB, Teitelbaum SL, Siskind J, Meisel SJ, et al. 2007. Prenatal organophosphate metabolite and organochlorine levels and performance on the Brazelton Neonatal Behavioral Assessment Scale in a multiethnic pregnancy cohort. Am J Epidemiol 165(12):1397-1404.

Eskenazi B, Harley K, Bradman A, Weltzien E, Jewell NP, Barr DB, et al. 2004. Association of in utero organophosphate pesticide exposure and fetal growth and length of gestation in an agricultural population. Environ Health Perspect 112(10):1116-1124.

Eskenazi B, Huen K, Marks A, Harley KG, Bradman A, Barr DB, et al. 2010. PON1 and Neurodevelopment in Children from the CHAMACOS Study Exposed to Organophosphate Pesticides in Utero. Environ Health Perspect.

Eskenazi B, Marks AR, Bradman A, Harley K, Barr DB, Johnson C, et al. 2007. Organophosphate pesticide exposure and neurodevelopment in young Mexican-American children. Environ Health Perspect 115(5):792-798.

Flanagan DP, Kaufman AS. 2004. Essentials of WISC-IV Assessment. Hoboken, New Jersey: John Wiley & Sons, Inc.

Jansen KL, Cole TB, Park SS, Furlong CE, Costa LG. 2009. Paraoxonase 1 (PON1) modulates the toxicity of mixed organophosphorus compounds. Toxicol Appl Pharmacol 236(2):142-153.

Lee BW, London L, Paulauskis J, Myers J, Christiani DC. 2003. Association between human paraoxonase gene polymorphism and chronic symptoms in pesticide-exposed workers. J Occup Environ Med 45(2):118-122.

Li WF, Costa LG, Richter RJ, Hagen T, Shih DM, Tward A, et al. 2000. Catalytic efficiency determines the in-vivo efficacy of PON1 for detoxifying organophosphorus compounds. Pharmacogenetics 10(9):767-779.

Lu C, Barr DB, Pearson MA, Waller LA. 2008. Dietary intake and its contribution to longitudinal organophosphorus pesticide exposure in urban/suburban children. Environ Health Perspect 116(4):537-542.

Marks AR, Harley K, Bradman A, Kogut K, Barr DB, Johnson C, et al. 2010. Organophosphate Pesticide Exposure and Attention in Young Mexican-American Children. Environ Health Perspect.

Nash D, Mostashari F, Fine A, Miller J, O'Leary D, Murray K, et al. 2001. The outbreak of West Nile virus infection in the New York City area in 1999. N Engl J Med 344(24):1807-1814.

Nielsen SS, McKean-Cowdin R, Farin FM, Holly EA, Preston-Martin S, Mueller BA. 2010. Childhood brain tumors, residential insecticide exposure, and pesticide metabolism genes. Environ Health Perspect 118(1):144-149.

O'Sullivan BC, Lafleur J, Fridal K, Hormozdi S, Schwartz S, Belt M, et al. 2005. The effect of pesticide spraying on the rate and severity of ED asthma. Am J Emerg Med 23(4):463-467.

Phillips DL, Pirkle JL, Burse VW, Bernert JT, Jr., Henderson LO, Needham LL. 1989. Chlorinated hydrocarbon levels in human serum: effects of fasting and feeding. Arch Environ Contam Toxicol 18(4):495-500.

Rauh VA, Garfinkel R, Perera FP, Andrews HF, Hoepner L, Barr DB, et al. 2006. Impact of prenatal chlorpyrifos exposure on neurodevelopment in the first 3 years of life among inner-city children. Pediatrics 118(6):e1845-1859.

Richter RJ, Jarvik GP, Furlong CE. 2009. Paraoxonase 1 (PON1) status and substrate hydrolysis. Toxicol Appl Pharmacol 235(1):1-9.

Stout DM, 2nd, Bradham KD, Egeghy PP, Jones PA, Croghan CW, Ashley PA, et al. 2009. American Healthy Homes Survey: a national study of residential pesticides measured from floor wipes. Environ Sci Technol 43(12):4294-4300.

Williams MK, Rundle A, Holmes D, Reyes M, Hoepner LA, Barr DB, et al. 2008. Changes in pest infestation levels, self-reported pesticide use, and permethrin exposure during pregnancy after the 2000-2001 U.S. Environmental Protection Agency restriction of organophosphates. Environ Health Perspect 116(12):1681-1688.

Wolff MS, Deych E, Ojo F, Berkowitz GS. 2005. Predictors of organochlorines in New York City pregnant women, 1998-2001. Environ Res 97(2):170-177.

Wolff MS, Engel S, Berkowitz G, Teitelbaum S, Siskind J, Barr DB, et al. 2007. Prenatal pesticide and PCB exposures and birth outcomes. Pediatr Res 61(2):243-250.

Young JG, Eskenazi B, Gladstone EA, Bradman A, Pedersen L, Johnson C, et al. 2005. Association between in utero organophosphate pesticide exposure and abnormal reflexes in neonates. Neurotoxicology 26(2):199-209.

Zhang X, Driver JH, Li Y, Ross JH, Krieger RI. 2008. Dialkylphosphates (DAPs) in fruits and vegetables may confound biomonitoring in organophosphorus insecticide exposure and risk assessment. J Agric Food Chem 56(22):10638-10645.

Table 1. Characteristics of the Mount Sinai Children's Environmental Health Study, Mount Sinai Medical Center 1998-2002

	Original Enrolled Cohort (N = 404)		12 month Follow-up (N = 200)		24 month Follow-up (N = 276)		6 - 9 year Follow-up (N = 169)	
	N	%	N	%	N	%	N	%
Maternal Age at delivery								
< 20 years	142	35.2	57	28.5	96	34.8	54	31.9
20-24 years	132	32.7	56	28.0	83	30.1	56	33.1
25-29 years	44	10.9	30	15.0	34	12.3	25	14.8
30-34 years	64	15.8	39	19.5	43	15.6	19	11.2
≥ 35 years	22	5.4	18	9.0	20	7.2	15	8.9
Race/Ethnicity								
White	86	21.29	57	28.5	63	22.8	31	18.3
Black	112	27.72	52	26.0	74	26.8	47	27.8
Hispanic	200	49.50	89	44.5	136	49.3	88	52.1
Other	6	1.49	2	1.0	3	1.1	3	1.8
Marital Status								
Married	117	29.0	71	35.5	81	29.4	38	22.5
Living with baby's father	98	24.3	41	20.5	62	22.5	40	23.7
Single	189	46.8	88	44.0	133	48.2	91	53.9
Education								
< High School	118	29.4	50	25.0	78	28.3	46	27.2
High School graduate	83	20.7	35	17.5	55	19.9	36	21.3
Some college	103	25.6	49	24.5	70	25.4	51	30.2
≥ Bachelor's degree	98	24.4	66	33.0	73	26.5	36	21.3
Alcohol Use during Pregnancy	59	14.0	31	16.0	36	13.4	28	16.9
Duration of Breastfeeding								
< 1 month	140	42.2	74	37.0	122	44.2	73	43.5
1-3 months	71	21.4	45	22.5	56	20.3	36	21.4
≥ 4 months	121	36.5	81	40.5	98	35.5	59	35.1
Any organophosphate biomarker level	383	94.8	190	95.0	267	96.7	165	99.0
Maternal *PON1* Q192R								
QQ	120	30.9	63	33.3	78	30.2	46	28.2
QR	174	44.7	83	43.9	119	46.1	78	47.9
RR	95	24.4	43	22.8	61	23.6	39	23.9
Maternal paraoxonase enzyme activity (units/ml)								
2964 – 9576 (Tertile 1)	130	33.9	69	37.5	91	35.7	57	34.8
9700 – 11660 (Tertile 2)	123	32.1	51	27.7	81	31.8	43	26.2
11665 – 20000 (Tertile 3)	130	33.9	64	34.8	83	32.6	64	39.0

Table 2. Prenatal Organophosphate Biomarker Levels and 12-month BSID-II Mental Development Index in the Mount Sinai Children's Environmental Health Study

		Combined Race/Ethnicity [a] (N = 149)		Black/Hispanic Subjects [b] (N = 111)		White Subjects [b] (N = 38)		
Organophosphate Biomarkers		**Adjusted Mean MDI**	**95% CI**	**Adjusted Mean MDI**	**95% CI**	**Adjusted Mean MDI**	**95% CI**	**interaction p-value**
ΣDAP	**T3**	96.1	93.1, 99.0	91.5	88.3, 94.7	103.7	98.5, 108.8	< 0.001
	T2	95.8	92.5, 99.1	94.4	91.2, 97.5	95.9	90.6, 101.3	
	T1	97.0	93.7, 100.3	96.2	92.9, 99.4	92.0	85.4, 98.7	
	$\log_{10}$ Beta	(-1.00)	(-3.28, 1.28)	(-3.29)	(-5.88, -0.70)	(4.77)	(0.69, 8.86)	0.001
ΣDEP	**T3**	97.5	94.3, 100.6	95.2	91.9, 98.6	100.6	94.6, 106.5	0.82
	T2	95.4	92.3, 98.6	93.8	90.4, 97.1	96.8	90.8, 102.9	
	T1	95.9	92.9, 98.9	94.3	90.9, 97.6	97.3	91.8, 102.7	
	$\log_{10}$ Beta	(0.03)	(-2.23, 2.29)	(-0.33)	(-3.00 , 2.35)	(0.86)	(-3.16, 4.87)	0.62
ΣDMP	**T3**	96.1	93.4, 99.0	92.1	89.0, 95.2	103.3	97.9, 108.7	< 0.01
	T2	96.1	92.9, 99.3	94.2	91.0, 97.4	97.2	91.1, 102.6	
	T1	96.8	93.5, 100.0	96.3	93.0, 99.5	92.2	85.6, 98.7	
	$\log_{10}$ Beta	(-1.12)	(-3.14, 0.89)	(-3.35)	(-5.64 , -1.06)	(4.45)	(0.82, 8.08)	< 0.001
		Adjusted Mean PDI	**95% CI**	**Adjusted Mean PDI**	**95% CI**	**Adjusted Mean PDI**	**95% CI**	**interaction p-value**
ΣDAP	**T3**	92.5	88.5, 96.6	94.2	89.5, 98.9	90.8	83.3, 98.2	0.65
	T2	96.6	92.1, 101.1	97.5	93.0, 102.1	97.0	89.2, 104.7	
	T1	95.3	90.9, 99.8	97.7	93.1, 102.4	90.0	80.5, 99.6	
	$\log_{10}$ Beta	(-0.52)	(-3.66, 2.62)	(-1.52)	(-5.21, 2.16)	(2.07)	(-3.83, 7.96)	0.31
ΣDEP	**T3**	93.6	89.3, 98.0	95.6	91.0, 100.2	91.7	83.5, 99.9	0.25
	T2	94.5	90.1, 98.9	95.9	91.2, 100.6	94.4	86.0, 102.7	
	T1	95.3	91.2, 99.5	97.7	93.1, 102.4	92.1	84.6, 99.6	
	$\log_{10}$ Beta	(-0.20)	(-3.28, 2.87)	(-0.48)	(-4.11, 3.16)	(0.46)	(-5.12, 6.03)	0.78
ΣDMP	**T3**	94.5	90.6, 98.5	96.4	92.0, 100.8	92.5	84.9, 100.2	0.83
	T2	93.7	89.3, 98.0	94.5	90.1, 99.0	94.4	86.7, 102.1	
	T1	95.1	90.7, 99.5	97.8	93.2, 102.4	89.5	80.2, 98.8	
	$\log_{10}$ Beta	(-0.92)	(-3.68, 1.85)	(-1.81)	(-5.07, 1.45)	(1.36)	(-3.83, 6.56)	0.31

[a] General linear model adjusted for race/ethnicity, maternal age at enrollment, child sex, examiner, maternal PON1 enzyme activity, season of urine collection, laboratory batch, HOME Score, alcohol consumption during pregnancy, and urinary creatinine.
[b] General linear model adjusted for maternal age at enrollment, child sex, examiner, maternal PON1 enzyme activity, season of urine collection, laboratory batch, HOME Score, alcohol consumption during pregnancy, and urinary creatinine, and including a biomarker-race interaction term.

Table 3 *PON1 Q192R* Interaction with Total Dialkyl and Dimethylphosphate Biomarker levels on the BISD-II Mental Development Index in the Mount Sinai Children's Environmental Health Study

	12-MONTH BSID-II Black/Hispanic Subjects N = 110[c]					24-MONTH BSID-II Total Population N = 191				
	PON1 192 QR/RR (FAST) N = 82		*PON1* 192 QQ (SLOW)[b] N = 28			*PON1* 192 QR/RR (FAST) N = 140		*PON1* 192 QQ (SLOW) N = 57		
	log_{10} Beta	95% CI	log_{10} Beta	95% CI	interaction p-value	log_{10} Beta	95% CI	log_{10} Beta	95% CI	interaction p-value
ΣDAP[a]	5.45	-0.79, 11.69	-4.71	-7.59, -1.83	<0.01	-1.04	-6.06, 3.99	-1.27	-4.40, 1.84	0.93
ΣDEP[a]	3.55	-1.14, 8.23	-1.60	-4.99, 1.79	0.08	-0.55	-4.79, 3.70	-0.15	-3.51, 3.21	0.88
ΣDMP[a]	2.52	-2.71, 7.74	-4.30	-6.89, -1.71	0.02	0.12	-4.17, 4.42	-0.48	-3.27, 2.30	0.81

[a] General linear model adjusted for maternal age at enrollment, child sex, examiner, HOME Score, alcohol consumption during pregnancy, laboratory batch, season of urine collection, urinary creatinine, and including a biomarker-*PON1* Q192R genotype interaction. The 24-month model was additionally adjusted for maternal race/ethnicity.
[b] Note that in this category, 7 are black and the remainder Hispanic.
[c] Note that 1 subject identified mixed ethnicity

Table 4 Prenatal Organophosphate Biomarker Levels and Psychometric Intelligence at 6-9 years in the Mount Sinai Children's Environmental Health Study

	$\log_{10}$ ΣDAP			$\log_{10}$ ΣDEP			$\log_{10}$ ΣDMP		
Combined Populations (6-9 years)[a]	**N**	**Beta**	**95% CI**	**N**	**Beta**	**95% CI**	**N**	**Beta**	**95% CI**
Full Scale IQ	140	-1.39	-4.54, 1.77	140	-2.89	-6.15, 0.36	142	-0.46	-3.17, 2.26
Perceptual Reasoning		-2.36	-6.04, 1.31		-3.51	-7.31, 0.30		-1.15	-4.31, 2.02
Verbal Comprehension		-0.42	-3.45, 2.62		-1.20	-4.35, 1.96		-0.05	-2.64, 2.54
	$\log_{10}$ ΣDAP			$\log_{10}$ ΣDEP			$\log_{10}$ ΣDMP		
WISC-IV (7-9 years) [a]	**N**	**Beta**	**95% CI**	**N**	**Beta**	**95% CI**	**N**	**Beta**	**95% CI**
Full Scale IQ	114	-1.10	-5.01, 2.81	114	-3.15	-7.19, 0.89	115	-0.39	-3.64, 2.86
Perceptual Reasoning		-2.39	-6.97, 2.19		-4.37	-9.10, 0.36		-1.24	-5.05, 2.57
Verbal Comprehension		0.56	-3.11, 4.23		-0.08	-3.91, 3.76		0.39	-2.65, 3.42
Processing Speed		-1.05	-5.57, 3.46		-2.11	-6.81, 2.59		-0.79	-4.52, 2.94
Working Memory		-0.53	-4.24, 3.18		-3.48	-7.29, 0.34		0.29	-2.81, 3.38
	$\log_{10}$ ΣDAP			$\log_{10}$ ΣDEP			$\log_{10}$ ΣDMP		
WPPSI-III (6 years) [a]	**N**	**Beta**	**95% CI**	**N**	**Beta**	**95% CI**	**N**	**Beta**	**95% CI**
Full Scale IQ	96	-1.14	-4.55, 2.28	96	-1.40	-5.27, 2.47	98	-0.56	-3.68, 2.56
Perceptual Reasoning		-2.07	-5.66, 1.52		-1.59	-5.68, 2.50		-1.46	-4.74, 1.83
Verbal Comprehension		-1.16	-4.59, 2.27		-2.27	-6.14, 1.60		-0.52	-3.67, 2.62
Processing Speed		-1.22	-5.12, 2.67		-1.85	-6.25, 2.56		-0.84	-4.35, 2.67

[a] Generalized linear models adjusted for sex, race/ethnicity, maternal education, language in the home, maternal PON1 enzymatic activity, alcohol use in pregnancy, batch season of urine collection, and urinary creatinine. Combined Population models additionally adjusted for whether the score came from the WISC-IV or WPPSI-III instrument.

Table 5 Joint Prenatal Organophosphate Biomarker and *PON1 Q192R* Effect on Combined IQ Domains at 6-9 years in the Mount Sinai Children's Environmental Health Study

	FSIQ *PON1* **192 QR/RR (Fast) N = 101**		**FSIQ** *PON1* **192 QQ (Slow) N = 39**		
	Beta	**95% CI**	**Beta**	**95% CI**	**interaction p-value**
log_{10} ΣDAP[a]	-0.66	-4.33, 3.00	-2.33	-8.40, 3.74	0.64
log_{10} ΣDEP[a]	-2.32	-6.49, 1.86	-3.13	-8.21, 1.96	0.80
log_{10} ΣDMP[a]	0.28	-2.89, 3.44	-1.79	-6.83, 3.25	0.49
	Perceptual Reasoning *PON1* **192 QR/RR (Fast)**		**Perceptual Reasoning** *PON1* **192 QQ (Slow)**		
	Beta	**95% CI**	**Beta**	**95% CI**	**interaction p-value**
log10 ΣDAP[a]	-0.56	-4.80, 3.68	-7.52	-14.53, -0.51	0.09
log10 ΣDEP[a]	-3.24	-8.11, 1.62	-4.80	-10.73, 1.13	0.68
log10 ΣDMP[a]	0.71	-2.96, 4.38	-6.15	-11.99, -0.31	0.05
	Verbal Comprehension *PON1* **192 QR/RR (Fast)**		**Verbal Comprehension** *PON1* **192 QQ (Slow)**		
	Beta	**95% CI**	**Beta**	**95% CI**	**interaction p-value**
log10 ΣDAP[a]	-0.33	-3.87, 3.20	-0.73	-5.12, 6.59	0.76
log10 ΣDEP[a]	-0.45	-4.51, 3.60	-1.20	-6.13, 3.74	0.81
log10 ΣDMP[a]	0.12	-2.93, 3.16	0.24	-4.60, 5.09	0.97

[a] Generalized linear models adjusted for sex, race/ethnicity, maternal education, language in the home, alcohol use in pregnancy, batch season of urine collection, urinary creatinine, and an indicator variable to designate the WISC-IV or WPPSI-III instrument.

Figure 1 Legend

Multivariate adjusted mean estimates and 95% confidence limits according to tertiles of exposure and *PON1* Q192R genotype are presented. Among the children of mothers with the *PON1* 192QQ genotype (black triangles), increasing tertile of ΣDAP, ΣDEP and ΣDMP exposure was generally associated with a monotonic decline in the combined WISC-IV/WPPSI-III FSIQ and Perceptual Reasoning domains, adjusted for sex, race/ethnicity, maternal education, language in the home, alcohol use in pregnancy, batch and season of urine collection, urinary creatinine, and an indicator variable to designate the WISC-IV or WPPSI-III instrument. There were no consistent patterns in the QR/RR genotype group (gray squares). There was considerable imprecision in all estimates. The 1st versus 3rd tertile contrasts for Perceptual Reasoning were significantly different at $p < 0.05$ for ΣDAP and ΣDMP. Overall these results suggest a role for genetic susceptibility in the deleterious effects of prenatal pesticide exposure.

Figure 1. FSIQ and Perceptual Reasoning scores at 6-9 years according to summed dialkylphosphate metabolite tertiles and *PON1* Q192R genotype (n = 140)