Published in final edited form as:
J Child Fam Stud. 2014 July 1; 23(5): 785–799. doi:10.1007/s10826-013-9731-4.

Neighborhood Social Context and Individual Polycyclic Aromatic Hydrocarbon Exposures Associated with Child Cognitive Test Scores

Gina S. Lovasi,
Department of Epidemiology, Columbia University Mailman School of Public Health, 722 W 168th St, Room 804, New York, NY 10032, USA

Nicolia Eldred-Skemp,
Department of Epidemiology, Columbia University Mailman School of Public Health, 722 W 168th St, Room 804, New York, NY 10032, USA

James W. Quinn,
Department of Epidemiology, Columbia University Mailman School of Public Health, 722 W 168th St, Room 804, New York, NY 10032, USA

Hsin-wen Chang,
Department of Biostatistics, Columbia University Mailman School of Public Health, New York, NY, USA

Virginia A. Rauh,
Department of Environmental Health Sciences, Columbia University Mailman School of Public Health, New York, NY, USA

Andrew Rundle,
Department of Epidemiology, Columbia University Mailman School of Public Health, 722 W 168th St, Room 804, New York, NY 10032, USA

Manuela A. Orjuela, and
Department of Environmental Health Sciences, Columbia University Mailman School of Public Health, New York, NY, USA

Frederica P. Perera
Department of Environmental Health Sciences, Columbia University Mailman School of Public Health, New York, NY, USA

Gina S. Lovasi: glovasi@columbia.edu

Abstract

Childhood cognitive and test-taking abilities have long-term implications for educational achievement and health, and may be influenced by household environmental exposures and

Correspondence to: Gina S. Lovasi, glovasi@columbia.edu.

Electronic supplementary material The online version of this article (doi:10.1007/s10826-013-9731-4) contains supplementary material, which is available to authorized users.

neighborhood contexts. This study evaluates whether age 5 scores on the Wechsler Preschool and Primary Scale of Intelligence-Revised (WPPSI-R, administered in English) are associated with polycyclic aromatic hydrocarbon (PAH) exposure and neighborhood context variables including poverty, low educational attainment, low English language proficiency, and inadequate plumbing. The Columbia Center for Children's Environmental Health enrolled African-American and Dominican-American New York City women during pregnancy, and conducted follow-up for subsequent childhood health outcomes including cognitive test scores. Individual outcomes were linked to data characterizing 1-km network buffers around prenatal addresses, home observations, interviews, and prenatal PAH exposure data from personal air monitors. Prenatal PAH exposure above the median predicted 3.5 point lower total WPPSI-R scores and 3.9 point lower verbal scores; the association was similar in magnitude across models with adjustments for neighborhood characteristics. Neighborhood-level low English proficiency was independently associated with 2.3 point lower mean total WPPSI-R score, 1.2 point lower verbal score, and 2.7 point lower performance score per standard deviation. Low neighborhood-level educational attainment was also associated with 2.0 point lower performance scores. In models examining effect modification, neighborhood associations were similar or diminished among the high PAH exposure group, as compared with the low PAH exposure group. Early life exposure to personal PAH exposure or selected neighborhood-level social contexts may predict lower cognitive test scores. However, these results may reflect limited geographic exposure variation and limited generalizability.

Keywords

Cognitive development; IQ; Neighborhood social context; Pollution; Children

Introduction

Childhood cognitive abilities have important long-term implications for educational achievement in childhood and adolescence (Deary et al. 2007; Fergusson et al. 2005; Neisser et al. 1996), income and occupation in adulthood (Fergusson et al. 2005; Sternberg et al. 2001), psychological well-being (Johnson et al. 2011), and life expectancy (Whalley and Deary 2001). In general, higher intelligence quotient (IQ) scores are associated with higher educational achievement and more positive outcomes throughout the life course (Braaten and Norman 2006). While cognitive abilities are partially heritable, they are also determined by environmental factors at the individual, family, and neighborhood levels. Longitudinal studies suggest younger children may be particularly susceptible to environmental influences on IQ, while heritability becomes a stronger predictor of IQ as children grow older, such that heritability of IQ is estimated at approximately 30 % in early childhood and increases to more than 50 % in adulthood (Brant et al. 2009; Deary et al. 2007; van Soelen et al. 2011).

Childhood socioeconomic status is a key determinant of health and wellbeing throughout the life course (Cohen et al. 2003; Leventhal and Brooks-Gunn 2003; Phelan et al. 2004; Pickett and Pearl 2001; Popay et al. 2003; Wen et al. 2003; Wheaton and Clarke 2003; Williams and Collins 2001), and may have relevance to cognitive development. Poverty reflects a set of interrelated conditions and pathways that extend beyond economic resources to affect human development (Huston and Bentley 2010). Children growing up in disadvantaged families and neighborhoods may have more toxic exposures through local air pollution, pesticide use, and dilapidated housing (Adamkiewicz et al. 2011; Evans and Kantrowitz 2002; Gee and Payne-Sturges 2004; Hutch et al. 2011; Jackson and Tester 2008; Ou et al. 2008; Perera et al. 2002, 2005), and may have less access to positive social conditions such as educational programs and parent–child interactions suitable for cultivating language development (Hanson et al. 2011; Huston and Bentley 2010; Patacchini and Zenou 2010; Slater et al. 1987). While family and neighborhood socioeconomic disadvantage have been linked to reduced child cognitive abilities as measured by IQ (Brooks-Gunn et al. 1996; Duncan et al. 1994; Johnson et al. 2011; Sastry and Pebley 2010), academic performance (Andreias et al. 2010; Hanson et al. 2011; Sastry and Pebley 2010), or language and intellectual deficits (Lloyd et al. 2010; Sharkey and Elwert 2011; Vaden-Kiernan et al. 2010), less is understood about the relationships among the specific environmental and social exposures that may predict cognitive development.

Environmental exposures may disproportionately influence the cognitive development of children growing up in disadvantaged environments (Rowe et al. 1999; Turkheimer et al. 2003). For instance, among twins in disadvantaged families, 60 % of variance in IQ was explained by the shared environment and close to 0 % of variance could be explained by heritability, while nearly the opposite was true among twins in affluent families (Turkheimer et al. 2003). Social and neighborhood conditions may exert independent influence on cognitive development, or may confound or moderate the associations between individual exposures and cognitive development.

We propose to examine this possibility while building on previous analyses showing that polycyclic aromatic hydrocarbons (PAHs) predict cognitive test scores (Perera et al. 2009a) in a Dominican-American and African-American birth cohort recruited from low-income areas of New York City. PAHs are a set of common airborne environmental pollutants that originate from incomplete combustion of fossil fuel, tobacco, or other organic materials (Bostrom et al. 2002; Delgado-Saborit et al. 2011). Fetuses and infants, especially those living in urban areas with high levels of air pollution, are highly susceptible to PAH exposure (Anderson et al. 2000; Council 1993; Dong et al. 2008; Edwards et al. 2010; Grandjean and Landrigan 2006; Herbstman et al. 2012; Jedrychowski et al. 2005; World Health Organization (1986); Perera et al. 2004, 2009a, b; Sanyal and Li 2007; Takeda et al. 2004; Weiland et al. 2011). We evaluate whether prenatal and early-life exposure to household or neighborhood settings confound the previously described association of PAH exposure with IQ, and explore the possibility that these neighborhood contexts independently predict age 5 IQ scores (Edwards et al. 2010; Perera et al. 2009a). We hypothesized that indicators of early life neighborhood disadvantage (poverty, low educational attainment, low English language proficiency, and inadequate plumbing in the area surrounding prenatal address) would independently predict lower cognitive test scores at age 5. In addition, we explored whether those with high PAH exposure would have increased susceptibility to local influences, as indicated by stronger neighborhood social context associations with cognitive test scores.

Method

Participants

The Columbia Center for Children's Environmental Health (CCCEH) birth cohort in New York City was designed to evaluate the effects of prenatal exposures to ambient and indoor pollutants on birth outcomes, neurocognitive development, asthma, and pro-carcinogenic damage (Perera et al. 2003, 2006; Rauh et al. 2004). Participants for this study were recruited during pregnancy from women registered for prenatal care at the New York Presbyterian Medical Center or Harlem Hospital. Pregnant African American and Dominican women between the ages of 18 and 35 were recruited by the 20th week of pregnancy, and their children were born between 1998 and 2006. Women were excluded if they reported current smoking or had a history of drug abuse, diabetes mellitus, hypertension, or known HIV infection, or if they had resided in the area for <1 year. All study procedures were approved by the institutional review board of Columbia University, and participating women provided informed consent.

Materials

Measures of Child Intelligence and Neurodevelopment—The Wechsler Preschool and Primary Scale of Intelligence-Revised (WPPSI-R) (Wechsler 1989) was used to assess intelligence and neurodevelopment at 5 years of age. The WPPSI-R is an individually administered, standardized measure that has been previously validated for ages 4–6 years (Flanagan and Alfonso 1995) and is shown to predict academic achievement (Kaplan 1996). Although important fluctuations in IQ occur in early childhood, moderate to strong correlations are observed over time (e.g., r = 0.77 for IQ at 4 years compared with 12 years later) (Braaten and Norman 2006; Sternberg et al. 2001). The WPPSI-R includes distinct performance (e.g. geometric design, picture completion, mazes) and verbal (e.g. comprehension, vocabulary, arithmetic) subscales (Wechsler 1989) that make up a full-scale composite IQ score. The scores are designed to have a population mean of 100, and a standard deviation of 15. The WPPSI-R was administered in English or Spanish based on the child's primary language. Scores from the Spanish version of the WPPSI-R have been excluded from this analysis because of differences in the Spanish and English language versions that may limit comparability, and as the Spanish version has not been validated for this population.

Housing and Neighborhood Characteristics—Indicators of building disrepair were self-reported by mothers during the prenatal interview (Rauh et al. 2002) and summed to create an index that included one point for each of the following problems: water damage, leaking pipes, peeling or flaking paint, holes in ceilings or walls, and lack of gas or electricity in the past 6 months. This index of disrepair, used in previous reports from this cohort (Lovasi et al. 2011; Rauh et al. 2002), ranged from 0 (no problems) to 4 (4 or more problems).

Neighborhood characteristics were defined using a 1-km network buffer around each prenatal home address. Addresses were geocoded using Geosupport, a software package developed by the New York City Department of City Planning. A one-kilometer network buffer (Hoehner et al. 2003; Lee and Moudon 2004; Moudon et al. 2006; Oliver et al. 2007) was constructed by following the pedestrian accessible street network for one kilometer in every possible direction from the geocoded address, and then joining these points together to create a polygon.

The characteristics of each neighborhood buffer were estimated using a spatial overlay with block group data from the US Census for the year 2000, summary file 3. Assessed characteristics included the percentage individual residents who were below the federal poverty line, the percentage of residents over age 25 who did not complete high school or equivalency, low neighborhood English language proficiency (defined as ‘linguistic isolation’ by the Census Bureau, meaning all household members 14 years old and over have at least some difficulty with English), and the percentage of housing units that were without complete plumbing. In addition, neighborhood racial composition (percent of residents reporting their race as black) and vacancies (percent of housing units that were vacant) were assessed but excluded from further consideration based on their strong correlations with low neighborhood English language proficiency ($|r| > 0.9$).

Polycyclic Aromatic Hydrocarbon (PAH) Exposure Measurement—Personal monitoring of prenatal PAH exposure was measured at a single point in time during the third trimester of pregnancy (details described previously) (Perera et al. 2003, 2009a). The women wore a small backpack holding a personal ambient air monitor for 2 consecutive days, and at night the women placed it near the bed. Pre-cleaned quartz microfiber filters and polyurethane foam cartridges were used to collect vapors and particles less than or equal to 2.5 Mg in diameter. The samples were analyzed at Southwest Research Institute for benz[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo-[*k*]fluoranthene, benzo[*a*]pyrene, indeno[1,2,3-*cd*]pyrene, disbenz[*a*,*h*]anthracene, and benzo[*g*,*h*,*i*]perylene. Quality control procedures included checking the flow rate, time, and completeness of documentation for each personal PAH monitor. All prenatal personal air samples had detectable levels of PAH (Perera et al. 2003). High exposure was defined as above the median of 2.26 ng/m^3 (Perera et al. 2009a).

Maternal Interview and Assessment—A 45-min prenatal interview was administered to each woman during the third trimester of her pregnancy, conducted by a trained bilingual interviewer in either English or Spanish. The interview, which was adapted from a related study in New York City (Perera et al. 1998), included questions on demographic and socioeconomic characteristics, lifetime residential history, smoking history, drug abuse and health history, and characteristics of the home environment. Tobacco smoke in the home was assessed by asking if there was a smoker in the household, and was validated in this sample using serum cotinine.

Maternal intelligence and the quality of the caretaking environment were assessed when the child was approximately 3 years old. The maternal intelligence assessment used the Test of Nonverbal Intelligence (TONI), Second Edition, a language-free measure of general intelligence that is considered to be relatively free of cultural bias (Brown et al. 1990). The quality of the caretaking environment was assessed using the Home Observation for Measurement of the Environment (HOME) instrument (Caldwall and Bradley 1979). The

HOME quality score integrates information on physical and interactive aspects of the environment, including parental interactions with the child and play materials that provide a variety of stimulation. The language of prenatal questionnaire administration and the home language recorded during the HOME inventory were used as indicators of household English language exposure.

Data Analysis

All analyses were conducted in Stata 12.1 using cluster robust standard errors that account for clustering of observations within community districts (59 named areas of NYC, governed by community boards). To facilitate comparisons across models, each neighborhood characteristic was re-scaled to have a standard deviation of 1. Differences in the tables can be interpreted as the contrast for children whose prenatal neighborhoods differed by 1 standard deviation. Adjusted models included the following covariates: sex, ethnicity, maternal education, maternal IQ score, environmental tobacco smoke exposure in the home, quality of the caretaking environment, and household English language exposure. Interactions were explored by examining continuous neighborhood predictors in PAH-exposure stratified models, with interaction p values based on Wald tests of an interaction term added to models in the full study sample.

Additional analyses adjusted for post-natal PAH metabolites, used age 3 home address (instead of prenatal address) to define neighborhood characteristics, or accounted for incomplete follow-up using inverse probability weighting (Hernan et al. 2004) (see Electronic Supplementary Material). Potential bias due to incomplete follow-up was addressed through inverse probability weighting as a sensitivity analysis. Inverse probability weights were estimated using logistic regression models predicting successful follow-up and completion of the WPPSI-R test at age 5. The logistic model was evaluated using a Hosmer–Lemeshow test and visual inspection across deciles, both of which suggested good fit to the data. Inverse probability weights ranged from 1.1 to 6.3.

Results

Of the 727 children enrolled, 326 (45 %) had complete data on prenatal exposure to PAH using personal monitors, prenatal neighborhood characteristics, and a WPPSI-R test completed in English at age 5 (Table 1). Dominican children and those with less household English language exposure were more likely to be excluded based on language of WPPSI-R test administration.

Total PAH exposure was not significantly correlated with measured neighborhood characteristics (Table 2). The highest correlation among these neighborhood characteristics was between low neighborhood educational attainment and low neighborhood English language proficiency ($r = 0.85$).

A previous report from this cohort using comparable methods included 249 children who had completed the age 5 assessments at the time of analysis (Perera et al. 2009a). At that time, those with high PAH exposure were reported to have a 4.3 point lower total score and a 4.7 point lower verbal score (both with $p < 0.01$). In the present analysis of 277 children with complete covariate data, those with high PAH exposure once again had lower total and verbal scores, although the magnitude of the difference was somewhat attenuated following the inclusion of more recently tested children (Tables 3 and 4); the association was statistically significant for both total and verbal scores, with a mean difference of 3.5 total points and 3.9 verbal points between high and low PAH exposure groups defined by a median split ($p < 0.05$). The association of prenatal PAH with total and verbal test score was somewhat attenuated following adjustment for low neighborhood-level English proficiency (Tables 3, 4, Model 5).

Neighborhood limited English language proficiency was associated with lower WPPSI-R total, verbal, and performance IQ scores (Tables 3, 4, 5, Model 5). Each standard deviation decrease in English proficiency was associated with a 2.3 point decrease in total WPPSI-R score (95 % CI −3.0 to −1.5) a 1.2 point lower verbal score (95 % CI −2.4 to −0.1), and a 2.7 point lower performance score (95 % CI −3.8 to −1.8). Low neighborhood-level educational attainment was associated with lower performance IQ scores, but was not significantly associated with total or verbal scores (Tables 3, 4, 5).

Each neighborhood characteristic was also considered within low and high PAH exposure strata, with a test for interaction (Table 6). Several of the associations between neighborhood characteristics and cognitive test scores were stronger within the low PAH exposure stratum.

Sensitivity analyses were considered using urinary PAH metabolites collected at age 3 as an additional adjustment, using age 3 addresses for estimation of neighborhood characteristics, or using inverse probability weighting to account for loss to follow-up (see Electronic Supplementary Material). More than half of the cohort participants (54 %) had moved between recruitment and the year 3 visit. When characteristics of a 1-km network buffer around each year 3 address were used to predict age 5 cognitive test scores, some associations were somewhat attenuated. Associations with high prenatal PAH were attenuated following inverse probability weighting, becoming non-significant. However, the association of low neighborhood English proficiency with lower total and performance test scores, remained statistically significant across all three of these sensitivity analyses.

Discussion

Neighborhood-level building dilapidation and low English language proficiency predicted lower total, verbal, and performance IQ score at age 5. Even after accounting for loss to follow-up using inverse probability weighting, low English language proficiency was significantly associated with age 5 cognitive test scores. High prenatal PAH exposure predicted lower total and verbal IQ score at age 5. Measured neighborhood characteristics did not appear to substantially confound the effect of PAH exposure on verbal IQ score; although the results were attenuated to non-significance they remained similar in direction and magnitude. The present findings suggest that early life exposure to neighborhood social disadvantages are associated with lower test scores at age 5, which may have detrimental effects on access to educational opportunities and health outcomes later in life. The associations of neighborhood social context with IQ tended to be similar or stronger among children with low PAH exposure.

Dilapidated housing, low neighborhood-level educational attainment and low neighborhood-level English language proficiency had the hypothesized association with lower age 5 IQ scores, but this was largely restricted to the performance sub-scale. The association may reflect the presence of multiple exposures to immigrants and minority families with limited English skills who are more likely to live in crowded housing (Burr et al. 2010; Standish et al. 2010), have exposure to secondhand smoke (Baezconde-Garbanati et al. 2011), experience food insecurity (Cutts et al. 2011; Standish et al. 2010), and develop poor overall health (Helm et al. 2010). Others have likewise found infrastructure and neighborhood-level problems to be associated with poor child development, educational and health outcomes (Evans 2006; Grady 2011; Helm et al. 2010; Patacchini and Zenou 2010; Tarter et al. 2009). However, we did not find consistent support for the hypotheses that neighborhood poverty or infrastructure problems represented by inadequate plumbing in the neighborhood would be associated with lower scores. The lack of association may reflect limited variation in neighborhood context in the recruitment area, as Dominican and African American study participants were recruited from low-income areas of Northern Manhattan and the Bronx, which may limit our statistical power to detect associations with measured neighborhood characteristics such as poverty or infrastructure in the neighborhood area.

These findings are somewhat consistent with previous studies showing that prenatal and early life exposure to family and neighborhood disadvantage variables may be linked to child IQ (Brooks-Gunn et al. 1996; Duncan et al. 1994; Johnson et al. 2011), language and cognitive development (Lloyd et al. 2010; Sharkey and Elwert 2011; Vaden-Kiernan et al. 2010), and academic performance (Andreias et al. 2010; Hanson et al. 2011). However, the exact relationship of disadvantage and childhood IQ is varied—one study discovered that a combination of maternal reading scores and neighborhood income levels accounted for a large portion of educational achievement in children (Sastry and Pebley 2010), while another suggested that neighborhood quality plays a bigger role in the educational achievement of children from low-educated families, while family characteristics play a bigger role in the child’s achievement for high-educated families (Patacchini and Zenou 2010).

Results from this New York City birth cohort also found a significant association of low neighborhood English language proficiency with total IQ. This finding should be understood in the context of other evidence for beneficial health and academic outcomes associated with neighborhood exposure to one’s native language and culture, especially among foreign-born Hispanics (Fernandez and Nielsen 1986; Park et al. 2008). One study found neighborhood collective efficacy and low neighborhood English proficiency to have protective effects against depression among foreign-born Latinos who had resided in the U.S. for at least 15 years (Vega et al. 2011). However, many studies show mixed health effects of acculturation that vary depending on different circumstances, such as amount of time spent in the U.S. and proficiency in English (Abraido-Lanza et al. 2005; Franzini et al. 2001; Gallo et al. 2009; Kao et al. 1995; Scribner 1996). Children living in limited English households or neighborhoods have fewer opportunities to speak and develop better English language skills, which may lead to fewer educational opportunities and put them at greater risk for lower academic performance (Hanson et al. 2011; Matute-Bianchi 1986; Pong and Hao 2007), poor health (Flores et al. 2005), and other barriers to inclusion in society (Hernandez et al.

2008; Huston and Bentley 2010) later in life. The observed association between low neighborhood-level English language proficiency and IQ test scores in this study was particularly pronounced for the performance scale, potentially reflecting a difficulty in understanding and following test directions in English. However, we do not have a clear picture for why such an association, if causal, would be smaller in magnitude for the verbal subscale of the WPPSI-R. The neighborhood-level limited English proficiency measure is challenging to interpret in light of strong correlations with excluded neighborhood characteristics (racial composition and vacancies), but was more strongly related to cognitive test scores than these excluded variables.

Key strengths of this birth cohort study include the availability and simultaneous consideration of both prenatal personal PAH and neighborhood address data, the prospective design with both pre- and post-natal time points, the inclusion of key potential confounders such as maternal IQ and household English usage, and the use of a validated cognitive assessment. In addition, our objective neighborhood definition, 1-km network buffers, had the advantage of placing each child in the center of her own neighborhood and accounting for major boundaries to pedestrian travel.

However, our study is also limited by its observational design, restricting our ability to make causal inference. Furthermore, the cohort includes Dominican and African American families in low-income neighborhoods of New York City, limiting geographic variability and generalizability. Generalizability is also limited by the exclusion of high risk women from the cohort based on reported substance use and medical conditions, births that occurred before third trimester recruitment, and the exclusion of children who took a different and non-comparable Spanish version of the WPPSI-R due to limited English proficiency. The relatively small population size also limits the statistical power available, and particularly limits our ability to assess statistical interactions. The high correlations among some neighborhood characteristics limited the number of characteristics we were able to examine, and limits our ability to make specific conclusions about low neighborhood English language proficiency, since it was also highly correlated with other neighborhood characteristics that were excluded from the analyses. Finally, any measurement error may attenuate or bias the observed associations. Measurement error in the outcome measure, IQ scores at age 5, is a concern, and this measure does not perfectly predict later life intelligence or educational achievement (Braaten and Norman 2006; Flanagan and Alfonso 1995). Additionally, the predictive validity of IQ scores in early and middle childhood may be modified by disadvantaged family, home and neighborhood settings (Breslau et al. 2001; Cohen and Parmelee 1983; Sameroff et al. 1993).

Summary and Conclusions

This study provides insight into the importance and interrelationship of multiple early childhood exposures to neighborhood disadvantage on cognitive development. In particular, future research is indicated to investigate early-life language exposures and other aspects of the social environment in one's neighborhood as predictors of cognitive test scores and access to educational opportunities. More generally, longitudinal research should be conducted on the role of neighborhood context on chemical toxicant exposures and health and developmental outcomes in other populations and settings to inform future public health and urban planning efforts.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

The authors would like to thank the investigators of the Built Environment and Health project and the research staff and study participants at the Columbia Center for Children's Environmental Health. The Columbia Center for Children's Environmental Health is supported by the National Institute of Environmental Health Sciences (http://www.niehs.nih.gov/; grants 5P01ES009600, 5R01ES008977, 5R01ES11158, 5R01ES012468, R01 ES014393, R01ES13163, P30 ES009089 and 5R01ES10165), the US Environmental Protection Agency (http://www.epa.gov/; grants R827027, RD832141, and RD834509), Irving General Clinical Research Center (http://www.ctsasharecenter.org/center/irving-institute-clinical-and-translational-research; grant RR00645), the John and Wendy Neu Family Foundation, the trustees of the Blanchette Hooker Rockefeller Fund, the Educational Foundation of America (http://www.efaw.org/), the Johnson Family Foundation (http://www.jffnd.org/), the Marisla Foundation (https://online.foundationsource.com/public/home/marisla), the John Merck Fund (http://www.jmfund.org/), New York Community Trust (http://www.nycommunitytrust.org/), and the New York Times Company Foundation (http://www.nytco.com/company/foundation/). This work was also supported by a career development award from the National Institutes of Health (http://www.nih.gov/; grant K01HD067390).

References

Abraido-Lanza AF, Chao MT, Florez KR. Do healthy behaviors decline with greater acculturation? Implications for the Latino mortality paradox. Social Science and Medicine. 2005; 61(6):1243–1255.10.1016/j.socscimed.2005.01.016 [PubMed: 15970234]

Adamkiewicz G, Zota AR, Fabian MP, Chahine T, Julien R, Spengler JD, et al. Moving environmental justice indoors: Understanding structural influences on residential exposure patterns in low-income communities. American Journal of Public Health. 2011; 101(Suppl 1):S238–S245.10.2105/AJPH.2011.300119 [PubMed: 21836112]

Anderson LM, Diwan BA, Fear NT, Roman E. Critical windows of exposure for children's health: Cancer in human epidemiological studies and neoplasms in experimental animal models. Environmental Health Perspectives. 2000; 108(Suppl 3):573–594. [PubMed: 10852857]

Andreias L, Borawski E, Schluchter M, Taylor HG, Klein N, Hack M. Neighborhood influences on the academic achievement of extremely low birth weight children. Journal of Pediatric Psychology. 2010; 35(3):275–283.10.1093/jpepsy/jsp057 [PubMed: 19584171]

Baezconde-Garbanati LA, Weich-Reushe K, Espinoza L, Portugal C, Barahona R, Garbanati J, et al. Secondhand smoke exposure among Hispanics/Latinos living in multiunit housing: Exploring barriers to new policies. American Journal of Health Promotion. 2011; 25(5 Suppl):S82–S90.10.4278/ajhp.100628-QUAL-219 [PubMed: 21510793]

Bostrom CE, Gerde P, Hanberg A, Jernstrom B, Johansson C, Kyrklund T, et al. Cancer risk assessment, indicators, and guidelines for polycyclic aromatic hydrocarbons in the ambient air. Environmental Health Perspectives. 2002; 110(Suppl 3):451–488. [PubMed: 12060843]

Braaten EB, Norman D. Intelligence (IQ) testing. Pediatrics in Review. 2006; 27(11):403–408. [PubMed: 17079505]

Brant AM, Haberstick BC, Corley RP, Wadsworth SJ, DeFries JC, Hewitt JK. The developmental etiology of high IQ. Behavior Genetics. 2009; 39(4):393–405.10.1007/s10519-009-9268-x [PubMed: 19377873]

Breslau N, Chilcoat HD, Susser ES, Matte T, Liang KY, Peterson EL. Stability and change in children's intelligence quotient scores: A comparison of two socioeconomically disparate communities. American Journal of Epidemiology. 2001; 154(8):711–717. [PubMed: 11590083]

Brooks-Gunn J, Klebanov PK, Duncan GJ. Ethnic differences in children's intelligence test scores: Role of economic deprivation, home environment, and maternal characteristics. Child Development. 1996; 67(2):396–408. [PubMed: 8625720]

Brown, L.; Sherbenou, RJ.; Johnsen, SK. Test of nonverbal intelligence: A language-free measure of cognitive ability. Austin: Pro-ed; 1990.

Burr JA, Mutchler JE, Gerst K. Patterns of residential crowding among Hispanics in later life: Immigration, assimilation, and housing market factors. Journals of Gerontology Series B, Psychological Sciences and Social Sciences. 2010; 65(6):772–782.10.1093/geronb/gbq069

Caldwall, BM.; Bradley, RH. Home observation for measurement of the environment. Little Rock, AR: University of Arkansas Press; 1979.

Cohen DA, Farley TA, Mason K. Why is poverty unhealthy? Social and physical mediators. Social Science and Medicine. 2003; 57(9):1631–1641. [PubMed: 12948572]

Cohen SE, Parmelee AH. Prediction of five-year Stanford-Binet scores in preterm infants. Child Development. 1983; 54(5):1242–1253. [PubMed: 6354631]

Council, NR. Pesticides in the diets of infants and children. Washington D.C.: National Academy Press; 1993.

Cutts DB, Meyers AF, Black MM, Casey PH, Chilton M, Cook JT, et al. US Housing insecurity and the health of very young children. American Journal of Public Health. 2011; 101(8):1508–1514.10.2105/ajph.2011.300139 [PubMed: 21680929]

Deary IJ, Strand S, Smith P, Fernandes C. Intelligence and educational achievement. Intelligence. 2007; 35(1):13–21.

Delgado-Saborit JM, Stark C, Harrison RM. Carcinogenic potential, levels and sources of polycyclic aromatic hydrocarbon mixtures in indoor and outdoor environments and their implications for air quality standards. Environment International. 2011; 37(2):383–392.10.1016/j.envint.2010.10.011 [PubMed: 21146218]

Dong W, Wang L, Thornton C, Scheffler BE, Willett KL. Benzo(a)pyrene decreases brain and ovarian aromatase mRNA expression in Fundulus heteroclitus. Aquatic Toxicology. 2008; 88(4):289–300.10.1016/j.aquatox.2008.05.006 [PubMed: 18571745]

Duncan GJ, Brooks-Gunn J, Klebanov PK. Economic deprivation and early childhood development. Child Development. 1994; 65(2 Spec No):296–318. [PubMed: 7516849]

Edwards SC, Jedrychowski W, Butscher M, Camann D, Kieltyka A, Mroz E, et al. Prenatal exposure to airborne polycyclic aromatic hydrocarbons and children's intelligence at 5 years of age in a prospective cohort study in Poland. Environmental Health Perspectives. 2010; 118(9):1326–1331.10.1289/ehp.0901070 [PubMed: 20406721]

Evans GW. Child development and the physical environment. Annual Review of Psychology. 2006; 57:423–451.10.1146/annurev.psych.57.102904.190057

Evans GW, Kantrowitz E. Socioeconomic status and health: The potential role of environmental risk exposure. Annual Review of Public Health. 2002; 23:303–331.10.1146/annurev.publhealth.23.112001.112349

Fergusson DM, Horwood LJ, Ridder EM. Show me the child at seven II: Childhood intelligence and later outcomes in adolescence and young adulthood. Journal of Child Psychology and Psychiatry. 2005; 46(8):850–858.10.1111/j.1469-7610.2005.01472.x [PubMed: 16033633]

Fernandez RM, Nielsen F. Bilingualism and Hispanic scholastic achievement: Some baseline results. Social Science Research. 1986; 15(1):43–70.

Flanagan DP, Alfonso VC. A critical review of the technical characteristics of new and recently revised intelligence tests for preschool children. Journal of Psychoeducational Assessment. 1995; 13(1):66–90.

Flores G, Abreu M, Tomany-Korman SC. Limited english proficiency, primary language at home, and disparities in children's health care: How language barriers are measured matters. Public Health Reports. 2005; 120(4):418–430. [PubMed: 16025722]

Franzini L, Ribble JC, Keddie AM. Understanding the Hispanic paradox. Ethnicity and Disease. 2001; 11(3):496–518. [PubMed: 11572416]

Gallo LC, Penedo FJ, Espinosa de los Monteros K, Arguelles W. Resiliency in the face of disadvantage: Do Hispanic cultural characteristics protect health outcomes? Journal of Personality. 2009; 77(6):1707–1746.10.1111/j.1467-6494.2009.00598.x [PubMed: 19796063]

Gee GC, Payne-Sturges DC. Environmental health disparities: A framework integrating psychosocial and environmental concepts. Environmental Health Perspectives. 2004; 112(17):1645–1653. [PubMed: 15579407]

Grady SC. Housing quality and racial disparities in low birth weight: A GIS assessment. Geospatial Analysis of Environmental Health. 2011; 4(2):303–318.

Grandjean P, Landrigan PJ. Developmental neurotoxicity of industrial chemicals. Lancet. 2006; 368(9553):2167–2178.10.1016/S0140-6736(06)69665-7 [PubMed: 17174709]

Hanson MJ, Miller AD, Diamond K, Odom S, Lieber J, Butera G, et al. Neighborhood community risk influences on preschool children's development and school readiness. Infants & Young Children. 2011; 24(1):87.

Helm D, Laussmann D, Eis D. Assessment of environmental and socio-economic stress. Central European Journal of Public Health. 2010; 18(1):3–7. [PubMed: 20586223]

Herbstman JB, Tang D, Zhu D, Qu L, Sjodin A, Li Z, et al. Prenatal exposure to polycyclic aromatic hydrocarbons, Benzo[a]Pyrene-DNA adducts and genomic DNA methylation in cord blood. Environmental Health Perspectives. 201210.1289/ehp.1104056

Hernan MA, Hernandez-Diaz S, Robins JM. A structural approach to selection bias. Epidemiology. 2004; 15(5):615–625. [PubMed: 15308962]

Hernandez DJ, Denton NA, Macartney SE. Children in Immigrant Families: Looking to Americaís futureí. Social Policy Report. 2008; 22(3):3–22.

Hoehner CM, Brennan LK, Brownson RC, Handy SL, Killingsworth R. Opportunities for integrating public health and urban planning approaches to promote active community environments. American Journal of Health Promotion. 2003; 18(1):14–20. [PubMed: 13677959]

Huston AC, Bentley AC. Human development in societal context. Annual Review of Psychology. 2010; 61(411–437):C411.10.1146/annurev.psych.093008.100442

Hutch DJ, Bouye KE, Skillen E, Lee C, Whitehead L, Rashid JR. Potential strategies to eliminate built environment disparities for disadvantaged and vulnerable communities. American Journal of Public Health. 2011; 101(4):587–595.10.2105/AJPH.2009.173872 [PubMed: 21389288]

Jackson RJ, Tester J. Environment shapes health, including children's mental health. Journal of the American Academy of Child and Adolescent Psychiatry. 2008; 47(2):129–131.10.1097/chi.0b013e31815d6944 [PubMed: 18216714]

Jedrychowski W, Galas A, Pac A, Flak E, Camman D, Rauh V, et al. Prenatal ambient air exposure to polycyclic aromatic hydrocarbons and the occurrence of respiratory symptoms over the first year of life. European Journal of Epidemiology. 2005; 20(9):775–782.10.1007/s10654-005-1048-1 [PubMed: 16170661]

Johnson W, Corley J, Starr JM, Deary IJ. Psychological and physical health at age 70 in the Lothian Birth Cohort 1936: Links with early life IQ, SES, and current cognitive function and neighborhood environment. Health Psychology. 2011; 30(1):1–11.10.1037/a0021834 [PubMed: 21299289]

Kao G, Tienda M. NORC, & Center, U. o. C. P. R. Optimism and achievement: The educational performance of immigrant youth. Social Science Quarterly-Austin. 1995; 76:1.

Kaplan C. Predictive validity of the WPPSI-R: A four year follow-up study. Psychology in the Schools. 1996; 33:211–220.

Lee C, Moudon AV. Physical activity and environment research in the health field: Implications for urban and transportation planning practice and research. Journal of Planning Literature. 2004; 19(2):147–181.

Leventhal T, Brooks-Gunn J. Moving to opportunity: An experimental study of neighborhood effects on mental health. American Journal of Public Health. 2003; 93(9):1576–1582.10.2105/AJPH.93.9.1576 [PubMed: 12948983]

Lloyd JE, Li L, Hertzman C. Early experiences matter: Lasting effect of concentrated disadvantage on children's language and cognitive outcomes. Health Place. 2010; 16(2):371–380.10.1016/j.healthplace.2009.11.009 [PubMed: 20022550]

Lovasi GS, Quinn JW, Rauh VA, Perera FP, Andrews HF, Garfinkel R, et al. Chlorpyrifos exposure and urban residential environment characteristics as determinants of early childhood neurodevelopment. American Journal of Public Health. 2011; 101(1):63–70.10.2105/AJPH.2009.168419 [PubMed: 20299657]

Matute-Bianchi ME. Ethnic identities and patterns of school success and failure among Mexican-descent and Japanese-American students in a California high school: An ethnographic analysis. American Journal of Education. 1986; 95:233–255.

Moudon AV, Lee C, Cheadle AD, Garvin C, Johnson D, Schmid TL, et al. Operational definitions of walkable neighborhood: Theoretical and empirical insights. Journal of Physical Activity and Health. 2006; 3(Suppl 1):S99–S117.

Neisser U, Boodoo G, Bouchard TJ Jr, Boykin AW, Brody N, Ceci SJ, et al. Intelligence: Knowns and unknowns. American Psychologist. 1996; 51(2):77.

Oliver LN, Schuurman N, Hall AW. Comparing circular and network buffers to examine the influence of land use on walking for leisure and errands. International Journal of Health Geographics. 2007; 6:41. [PubMed: 17883870]

Ou CQ, Hedley AJ, Chung RY, Thach TQ, Chau YK, Chan KP, et al. Socioeconomic disparities in air pollution-associated mortality. Environmental Research. 2008; 107(2):237–244.10.1016/j.envres.2008.02.002 [PubMed: 18396271]

Park Y, Neckerman KM, Quinn J, Weiss C, Rundle A. Place of birth, duration of residence, neighborhood immigrant composition and body mass index in New York City. International Journal of Behavioral Nutrition and Physical Activity. 2008; 5(1):19. [PubMed: 18394171]

Patacchini E, Zenou Y. Neighborhood effects and parental involvement in the intergenerational transmission of education. Documents de treball IEB. 2010; 47:1–45.

Perera FP, Illman SM, Kinney PL, Whyatt RM, Kelvin EA, Shepard P, et al. The challenge of preventing environmentally related disease in young children: Community-based research in New York City. Environmental Health Perspectives. 2002; 110(2):197–204. [PubMed: 11836150]

Perera FP, Li Z, Whyatt R, Hoepner L, Wang S, Camann D, et al. Prenatal airborne polycyclic aromatic hydrocarbon exposure and child IQ at age 5 years. Pediatrics. 2009a; 124(2):e195–e202.10.1542/peds.2008-3506 [PubMed: 19620194]

Perera FP, Rauh V, Tsai WY, Kinney P, Camann D, Barr D, et al. Effects of transplacental exposure to environmental pollutants on birth outcomes in a multiethnic population. Environmental Health Perspectives. 2003; 111(2):201–205. [PubMed: 12573906]

Perera FP, Rauh V, Whyatt RM, Tang D, Tsai WY, Bernert JT, et al. A summary of recent findings on birth outcomes and developmental effects of prenatal ETS, PAH, and pesticide exposures. Neurotoxicology. 2005; 26(4):573–587.10.1016/j.neuro.2004.07.007 [PubMed: 16112323]

Perera FP, Rauh V, Whyatt RM, Tsai WY, Tang D, Diaz D, et al. Effect of prenatal exposure to airborne polycyclic aromatic hydrocarbons on neurodevelopment in the first 3 years of life among inner-city children. Environmental Health Perspectives. 2006; 114(8):1287–1292. [PubMed: 16882541]

Perera F, Tang WY, Herbstman J, Tang D, Levin L, Miller R, et al. Relation of DNA methylation of 5’-CpG island of ACSL3 to transplacental exposure to airborne polycyclic aromatic hydrocarbons and childhood asthma. PLoS ONE. 2009b; 4(2):e4488.10.1371/journal.pone.0004488 [PubMed: 19221603]

Perera FP, Tang D, Tu YH, Cruz LA, Borjas M, Bernert T, et al. Biomarkers in maternal and newborn blood indicate heightened fetal susceptibility to procarcinogenic DNA damage. Environmental Health Perspectives. 2004; 112(10):1133–1136. [PubMed: 15238289]

Perera FP, Whyatt RM, Jedrychowski W, Rauh V, Manchester D, Santella RM, et al. Recent developments in molecular epidemiology: A study of the effects of environmental polycyclic aromatic hydrocarbons on birth outcomes in Poland. American Journal of Epidemiology. 1998; 147(3):309–314. [PubMed: 9482506]

Phelan JC, Link BG, Diez-Roux A, Kawachi I, Levin B. “Fundamental causes” of social inequalities in mortality: A test of the theory. Journal of Health and Social Behavior. 2004; 45(3):265–285. [PubMed: 15595507]

Pickett KE, Pearl M. Multilevel analyses of neighbourhood socioeconomic context and health outcomes: A critical review. Journal of Epidemiology and Community Health. 2001; 55(2):111–122. [PubMed: 11154250]

Pong S, Hao L. Neighborhood and school factors in the school performance of immigrants, Children1. International Migration Review. 2007; 41(1):206–241.

Popay J, Thomas C, Williams G, Bennett S, Gatrell A, Bostock L. A proper place to live: Health inequalities, agency and the normative dimensions of space. Social Science and Medicine. 2003; 57(1):55–69. [PubMed: 12753816]

Rauh VA, Chew GR, Garfinkel RS. Deteriorated housing contributes to high cockroach allergen levels in inner-city households. Environmental Health Perspectives. 2002; 110(Suppl 2):323–327. [PubMed: 11929744]

Rauh VA, Whyatt RM, Garfinkel R, Andrews H, Hoepner L, Reyes A, et al. Developmental effects of exposure to environmental tobacco smoke and material hardship among inner-city children. Neurotoxicology and Teratology. 2004; 26(3):373–385.10.1016/j.ntt.2004.01.002 [PubMed: 15113599]

Rowe DC, Jacobson KC, Van den Oord EJ. Genetic and environmental influences on vocabulary IQ: Parental education level as moderator. Child Development. 1999; 70(5):1151–1162. [PubMed: 10546338]

Sameroff AJ, Seifer R, Baldwin A, Baldwin C. Stability of intelligence from preschool to adolescence: The influence of social and family risk factors. Child Development. 1993; 64(1):80–97. [PubMed: 8436039]

Sanyal MK, Li YL. Deleterious effects of polynuclear aromatic hydrocarbon on blood vascular system of the rat fetus. Birth Defects Research, Part B: Developmental and Reproductive Toxicology. 2007; 80(5):367–373.10.1002/bdrb.20122

Sastry N, Pebley AR. Family and neighborhood sources of socioeconomic inequality in children's achievement. Demography. 2010; 47(3):777–800. [PubMed: 20879688]

Scribner R. Paradox as paradigm–the health outcomes of Mexican Americans. American Journal of Public Health. 1996; 86(3):303–305. [PubMed: 8604751]

Sharkey P, Elwert F. The legacy of disadvantage: multigenerational neighborhood effects on cognitive ability. American Journal of Sociology. 2011; 116(6):1934–1981.

Slater MA, Naqvi M, Andrew L, Haynes K. Neurodevelopment of monitored versus nonmonitored very low birth weight infants: The importance of family influences. Journal of Developmental and Behavioral Pediatrics. 1987; 8(5):278–285. [PubMed: 2445784]

Standish K, Nandi V, Ompad DC, Momper S, Galea S. Household density among undocumented Mexican immigrants in New York City. Journal of Immigrant and Minority Health. 2010; 12(3): 310–318.10.1007/s10903-008-9175-x [PubMed: 18709456]

Sternberg RJ, Bundy DA, Grigorenko E. The predictive value of IQ. Merrill-Palmer Quarterly. 2001; 47(1):1–41.

Takeda K, Tsukue N, Yoshida S. Endocrine-disrupting activity of chemicals in diesel exhaust and diesel exhaust particles. Environmental Sciences. 2004; 11(1):33–45. [PubMed: 15746887]

Tarter RE, Kirisci L, Gavaler JS, Reynolds M, Kirillova G, Clark DB, et al. Prospective study of the association between abandoned dwellings and testosterone level on the development of behaviors leading to cannabis use disorder in boys. Biological Psychiatry. 2009; 65(2):116–121.10.1016/j.biopsych.2008.08.032 [PubMed: 18930183]

Turkheimer E, Haley A, Waldron M, D'Onofrio B, Gottesman II. Socioeconomic status modifies heritability of IQ in young children. Psychological Science. 2003; 14(6):623–628. [PubMed: 14629696]

Vaden-Kiernan M, DíElio MA, OíBrien RW, Tarullo LB, Zill N, Hubbell-McKey R. Neighborhoods as a developmental context: A multilevel analysis of neighborhood effects on head start families and children. American Journal of Community Psychology. 2010; 45(1):49–67. [PubMed: 20066488]

van Soelen IL, Brouwer RM, van Leeuwen M, Kahn RS, Hulshoff Pol HE, Boomsma DI. Heritability of verbal and performance intelligence in a pediatric longitudinal sample. Twin Research and Human Genetics. 2011; 14(2):119–128.10.1375/twin.14.2.119 [PubMed: 21425893]

Vega WA, Ang A, Rodriguez MA, Finch BK. Neighborhood protective effects on depression in Latinos. American Journal of Community Psychology. 2011; 47:114–126. [PubMed: 21052825]

Wechsler, D. Wechsler Preschool and Primary Scale of Intelligence—Revised. San Antonio, TX: The Psychological Corporation; 1989.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Weiland K, Neidell M, Rauh V, Perera F. Cost of developmental delay from prenatal exposure to airborne polycyclic aromatic hydrocarbons. Journal of Health Care for the Poor and Underserved. 2011; 22(1):320–329.10.1353/hpu.2011.0012 [PubMed: 21317525]

Wen M, Browning CR, Cagney KA. Poverty, affluence, and income inequality: Neighborhood economic structure and its implications for health. Social Science and Medicine. 2003; 57(5):843–860. [PubMed: 12850110]

Whalley LJ, Deary IJ. Longitudinal cohort study of childhood IQ and survival up to age 76. BMJ. 2001; 322(7290):819. [PubMed: 11290633]

Wheaton B, Clarke P. Space meets time: Integrating temporal and contextual influences on mental health in early adulthood. American Sociological Review. 2003; 68:680–706.

Williams DR, Collins C. Racial residential segregation: A fundamental cause of racial disparities in health. Public Health Reports. 2001; 116(5):404–416. [PubMed: 12042604]

World Health Organization. Environmental Health Criteria. Vol. 59. Geneva, Switzerland: World Health Organization; 1986. Principles for evaluating health risks from chemicals during infancy and early childhood: The need for a special approach.

Table 1

Individual, household, and neighborhood characteristics

	Enrolled in prenatal sample (N = 727)	Prenatal PAH exposure and neighborhood assessed (N = 687)	WPPSI-R completed in English at age 5 years (N = 326)
Gestational age at birth, months	39.3 (1.4)	39.3 (1.4)	39.2 (1.5)
Male	48 %	49 %	49 %
Dominican	65 %	64 %	46 %
Black	35 %	36 %	54 %
Maternal education < high school	40 %	38 %	38 %
Maternal TONI score (raw)	20.6 (8.7)	20.7 (8.7)	21.7 (8.7)
Tobacco smoke in the home	34 %	34 %	39 %
Indicators of disrepair	1.2 (1.2)	1.2 (1.2)	1.2 (1.3)
HOME quality score	39.4 (6.3)	39.4 (6.2)	40.4 (5.8)
Prenatal Questionnaire in English	60 %	61 %	79 %
English primarily spoken in the home	43 %	43 %	59 %
Both English and Spanish in the home	10 %	10 %	12 %
High PAH		51 %	54 %
Total PAH		3.5 (6.6)	3.5 (4.0)
Total PAH, log-transformed		0.9 (0.8)	0.9 (0.7)
Percent poverty		35.5 (4.9)	35.5 (4.5)
Percent < high school education		44.1 (6.4)	42.7 (6.8)
Percent low English language proficiency		20.9 (9.2)	18.6 (9.6)
Percent inadequate plumbing		2.4 (0.4)	2.3 (0.4)
Age of WPPSI-R administration, months			60.7 (2.7)
Total WPPSI-R Score			98 (14)
WPPSI-R performance IQ score			104 (15)
WPPSI-R verbal IQ score			93 (14)

Values shown are percent or mean (SD); *TONI* test of nonverbal intelligence, second edition; *HOME* home observation for measurement of the environment, *PAH* polycyclic aromatic hydrocarbons; WPPSI-R wechsler preschool and primary scale of intelligence-revised

Table 2

Correlations among personal monitoring and neighborhood exposure data

	Total PAH	Disrepair	Poverty	<High school	Low English proficiency	Inadequate plumbing
Total PAH exposure, log-transformed	–					
Indicators of disrepair	**0.13**	–				
Neighborhood percent poverty	−0.01	−0.06	–			
Neighborhood percent < high school education	0.05	0.00	**0.38**	–		
Neighborhood percent low English proficiency	0.05	0.01	−0.04	**0.85**	–	
Neighborhood percent inadequate plumbing	0.08	0.02	**0.24**	**0.46**	**0.29**	–

PAH polycyclic aromatic hydrocarbons, values shown are correlation coefficients; bold face indicates statistical significance ($p < 0.05$); N = 326

Table 3

Main analyses of PAH exposure, household characteristics, and neighborhood characteristics as predictors of total WPSSI-R score at age 5 years

	Model 1 PAH only	Model 2 + household variables	Model 3 + neighborhood poverty	Model 4 + neighborhood education	Model 5 + neighborhood low English proficiency	Model 6 + neighborhood inadequate plumbing
Male						
β	**−3.13**	**−2.81**	**−2.81**	**−2.88**	**−3.24**	**−2.84**
95 % CI	**(−5.52 to −0.73)**	**(−5.30 to −0.32)**	**(−5.38 to −0.25)**	**(−5.42 to −0.35)**	**(−5.55 to −0.94)**	**(−5.24 to −0.45)**
Dominican						
β	−1.28	4.30	4.06	5.29	7.48	4.19
95 % CI	(−3.24 to 0.68)	(−5.29 to 13.90)	(−5.35 to 13.46)	(−5.06 to 15.65)	(−1.53 to 16.48)	(−5.64 to 14.02)
Maternal education < high school						
β	**−5.22**	**−5.51**	**−5.45**	**−5.56**	**−5.78**	**−5.40**
95 % CI	**(−8.00 to −2.44)**	**(−8.34 to −2.68)**	**(−8.49 to −2.40)**	**(−8.41 to −2.71)**	**(−8.53 to −3.03)**	**(−8.27 to −2.54)**
Maternal TONI score (raw)						
β	**0.27**	**0.18**	**0.18**	**0.16**	**0.16**	**0.19**
95 % CI	**(0.21 to 0.33)**	**(0.09 to 0.28)**	**(0.07 to 0.28)**	**(0.07 to 0.26)**	**(0.07 to 0.26)**	**(0.10 to 0.28)**
Tobacco smoke in the home						
β	1.83	−0.06	−0.13	−0.15	−0.13	0.03
95 % CI	(−0.71 to 4.36)	(−2.75 to 2.62)	(−2.92 to 2.67)	(−2.92 to 2.63)	(−2.91 to 2.65)	(−2.64 to 2.70)
HOME quality score						
β	**0.40**	**0.33**	**0.33**	**0.33**	**0.33**	**0.33**
95 % CI	**(0.27 to 0.53)**	**(0.18 to 0.47)**	**(0.18 to 0.47)**	**(0.19 to 0.47)**	**(0.19 to 0.47)**	**(0.18 to 0.48)**
High PAH						
β	**−3.45**	−3.42	−3.40	−3.20	−2.90	−3.48
95 % CI	**(−6.63 to −0.27)**	(−7.17 to 0.32)	(−7.06 to 0.27)	(−6.92 to 0.52)	(−6.97 to 1.16)	(−7.10 to 0.15)
Prenatal Questionnaire in English						
β		1.91	1.83	1.94	2.06	1.79
95 % CI		(−1.79 to 5.60)	(−1.83 to 5.50)	(−1.71 to 5.59)	(−1.65 to 5.77)	(−1.99 to 5.57)
English primarily spoken in the home						
β		7.57	7.59	7.64	7.82	7.61
95 % CI		(−5.73 to 20.87)	(−5.90 to 21.07)	(−5.93 to 21.21)	(−5.45 to 21.08)	(−5.61 to 20.83)
Both English and Spanish in the home						

NIH-PA Author Manuscript
NIH-PA Author Manuscript

	Model 1 PAH only	Model 2 + household variables	Model 3 + neighborhood poverty	Model 4 + neighborhood education	Model 5 + neighborhood low English proficiency	Model 6 + neighborhood inadequate plumbing
β		3.93	3.93	3.88	4.21	3.96
95 % CI		(−1.92 to 9.78)	(−2.06 to 9.93)	(−2.23 to 9.99)	(−1.77 to 10.19)	(−1.75 to 9.68)
Building dilapidation index						
β		0.04	0.02	0.03	0.02	0.03
95 % CI		(−0.81 to 0.89)	(−0.85 to 0.89)	(−0.83 to 0.89)	(−0.82 to 0.86)	(−0.82 to 0.88)
Neighborhood percent poverty						
β			−0.43			
95 % CI			(−2.39 to 1.54)			
Neighborhood percent <high school education						
β				−0.96		
95 % CI				(−2.13 to 0.20)		
Neighborhood percent low English proficiency						
β					**−2.28**	
95 % CI					**(−3.04 to −1.51)**	
Neighborhood percent inadequate plumbing						
β						0.35
95 % CI						(−0.91 to 1.62)

PAH polycyclic aromatic hydrocarbons, for which high values have defined as above the median of 2.26 ng/m^3; the building dilapidation index has a range from 0 to 4 based on the number of reported problems (e.g., holes in walls, leaking pipes); neighborhood characteristics (percent poverty, percent not completing high school, percent low English language proficiency, percent inadequate plumbing) have been estimated for a 1-km network buffer surrounding the prenatal home address; each neighborhood characteristic has been rescaled to a z-score such that the coefficients shown are for a 1 standard deviation increase; all regression models account for clustering within community districts and adjust the child's sex, ethnicity, maternal education, maternal IQ score, environmental tobacco smoke exposure in the home, quality of the caretaking environment, and home English language exposure; bold face indicates statistical significance ($p < 0.05$); N = 277

Table 4

Main analyses of PAH exposure, household characteristics, and neighborhood characteristics as predictors of WPSSI-R verbal subscale scores at age 5 years

	Model 1 PAH only	Model 2 + household variables	Model 3 + neighborhood poverty	Model 4 + neighborhood education	Model 5 + neighborhood low English proficiency	Model 6 + neighborhood inadequate plumbing
Male						
β	**−4.26**	**−3.81**	**−3.80**	**−3.78**	**−4.05**	**−3.90**
95 % CI	**(−7.00 to −1.52)**	**(−6.76 to −0.87)**	**(−6.60 to −1.00)**	**(−6.72 to −0.84)**	**(−6.79 to −1.32)**	**(−6.69 to −1.11)**
Dominican						
β	**−6.38**	−0.36	0.27	−0.75	1.36	−0.64
95 % CI	**(−8.83 to −3.93)**	(−11.05 to 10.33)	(−9.40 to 9.95)	(−11.59 to 10.08)	(−7.94 to 10.65)	(−11.44 to 10.17)
Maternal education < high school						
β	**−4.21**	**−4.41**	**−4.57**	**−4.39**	**−4.55**	**−4.15**
95 % CI	**(−6.44 to −1.98)**	**(−6.52 to −2.29)**	**(−6.72 to −2.42)**	**(−6.48 to −2.30)**	**(−6.61 to −2.49)**	**(−6.29 to −2.01)**
Maternal TONI score (raw)						
β	**0.13**	0.05	0.07	0.06	0.04	0.06
95 % CI	**(0.01 to 0.24)**	(−0.10 to 0.20)	(−0.08 to 0.22)	(−0.09 to 0.20)	(−0.12 to 0.20)	(−0.08 to 0.21)
Tobacco smoke in the home						
β	2.03	0.20	0.37	0.24	0.17	0.42
95 % CI	(−0.20 to 4.27)	(−2.75 to 3.16)	(−2.66 to 3.39)	(−2.73 to 3.21)	(−2.82 to 3.16)	(−2.53 to 3.37)
HOME quality score						
β	**0.53**	**0.44**	**0.44**	**0.44**	**0.44**	**0.44**
95 % CI	**(0.37 to 0.69)**	**(0.25 to 0.63)**	**(0.25 to 0.63)**	**(0.24 to 0.63)**	**(0.26 to 0.63)**	**(0.25 to 0.64)**
High PAH						
β	**−3.90**	**−4.08**	**−4.15**	**−4.17**	−3.80	**−4.21**
95 % CI	**(−6.98 to −0.81)**	**(−7.83 to −0.33)**	**(−7.83 to −0.46)**	**(−7.84 to −0.50)**	(−7.92 to 0.32)	**(−7.89 to −0.53)**
Prenatal Questionnaire in English						
β		1.85	2.03	1.83	1.93	1.57
95 % CI		(−0.72 to 4.42)	(−0.47 to 4.53)	(−0.76 to 4.43)	(−0.72 to 4.58)	(−1.15 to 4.28)
English primarily spoken in the home						
β		7.94	7.90	7.92	8.08	8.04
95 % CI		(−4.37 to 20.26)	(−4.16 to 19.95)	(−4.36 to 20.19)	(−4.16 to 20.32)	(−4.19 to 20.28)

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Model 1 PAH only	Model 2 + household variables	Model 3 + neighborhood poverty	Model 4 + neighborhood education	Model 5 + neighborhood low English proficiency	Model 6 + neighborhood inadequate plumbing
Both English and Spanish in the home					
β	3.86	3.87	3.88	4.01	3.93
95 % CI	(−2.30 to 10.02)	(−1.92 to 9.65)	(−2.15 to 9.91)	(−2.22 to 10.24)	(−1.97 to 9.83)
Building dilapidation index					
β	0.50	0.56	0.51	0.49	0.48
95 % CI	(−0.37 to 1.38)	(−0.29 to 1.41)	(−0.36 to 1.38)	(−0.39 to 1.37)	(−0.38 to 1.34)
Neighborhood percent poverty					
β		1.10			
95 % CI		(−0.25 to 2.45)			
Neighborhood percent < high school education					
β			0.38		
95 % CI			(−0.29 to 1.05)		
Neighborhood percent low English proficiency					
β				**−1.23**	
95 % CI				**(−2.37 to −0.10)**	
Neighborhood percent inadequate plumbing					
β					0.85
95 % CI					(−0.39 to 2.08)

PAH polycyclic aromatic hydrocarbons, for which high values have defined as above the median of 2.26 ng/m^3; the building dilapidation index has a range from 0 to 4 based on the number of reported problems (e.g., holes in walls, leaking pipes); neighborhood characteristics (percent poverty, percent not completing high school, percent low English language proficiency, percent inadequate plumbing) have been estimated for a 1-km network buffer surrounding the prenatal home address; each neighborhood characteristic has been rescaled to a z-score such that the coefficients shown are for a 1 standard deviation increase; all regression models account for clustering within community districts and adjust the child's sex, ethnicity, maternal education, maternal IQ score, environmental tobacco smoke exposure in the home, quality of the caretaking environment, and home English language exposure; bold face indicates statistical significance ($p < 0.05$); N = 277

Table 5

Main Analyses of PAH exposure, household characteristics, and neighborhood characteristics as predictors of WPSSI-R performance subscale scores at age 5 years

	Model 1 PAH only	Model 2 + household variables	Model 3 + neighborhood poverty	Model 4 + neighborhood education	Model 5 + neighborhood low English proficiency	Model 6 + neighborhood inadequate plumbing
Male						
β	−1.85	−1.72	−1.74	−1.88	−2.24	−1.71
95 % CI	(−4.97 to 1.27)	(−4.48 to 1.04)	(−4.64 to 1.16)	(−4.56 to 0.80)	(−4.92 to 0.45)	(−4.42 to 1.00)
Dominican						
β	**5.24**	**8.96**	**7.90**	**11.04**	**12.70**	**8.98**
95 % CI	**(2.56 to 7.93)**	**(3.13 to 14.79)**	**(1.62 to 14.18)**	**(3.66 to 18.41)**	**(6.05 to 19.35)**	**(2.80 to 15.15)**
Maternal education < high school						
β	**−5.24**	**−5.66**	**−5.39**	**−5.76**	**−5.98**	**−5.68**
95 % CI	**(−8.45 to −2.04)**	**(−9.10 to −2.22)**	**(−9.24 to −1.53)**	**(−9.27 to −2.25)**	**(−9.39 to −2.57)**	**(−9.22 to −2.13)**
Maternal TONI score (raw)						
β	**0.38**	**0.30**	**0.26**	**0.25**	**0.27**	**0.30**
95 % CI	**(0.30 to 0.46)**	**(0.20 to 0.39)**	**(0.14 to 0.38)**	**(0.14 to 0.36)**	**(0.18 to 0.36)**	**(0.19 to 0.40)**
Tobacco smoke in the home						
β	1.40	−0.17	−0.44	−0.34	−0.25	−0.18
95 % CI	(−1.29 to 4.08)	(−2.20 to 1.86)	(−2.31 to 1.43)	(−2.44 to 1.75)	(−2.41 to 1.91)	(−1.97 to 1.60)
HOME quality score						
β	**0.17**	**0.13**	**0.14**	**0.14**	**0.14**	**0.13**
95 % CI	**(0.06 to 0.29)**	**(0.03 to 0.24)**	**(0.04 to 0.25)**	**(0.04 to 0.25)**	**(0.03 to 0.25)**	**(0.03 to 0.24)**
High PAH						
β	−1.67	−1.36	−1.26	−0.89	−0.75	−1.36
95 % CI	(−4.89 to 1.55)	(−5.02 to 2.29)	(−4.61 to 2.10)	(−4.50 to 2.71)	(−4.61 to 3.10)	(−4.90 to 2.18)
Prenatal Questionnaire in English						
β		1.45	1.13	1.52	1.63	1.46
95 % CI		(−3.62 to 6.51)	(−4.26 to 6.53)	(−3.38 to 6.42)	(−3.33 to 6.59)	(−3.49 to 6.41)
English primarily Spoken in the home						
β		5.30	5.38	5.45	5.59	5.29
95 % CI		(−6.37 to 16.96)	(−6.84 to 17.59)	(−6.67 to 17.57)	(−6.05 to 17.23)	(−6.29 to 16.87)

	Model 1 PAH only	Model 2 + household variables	Model 3 + neighborhood poverty	Model 4 + neighborhood education	Model 5 + neighborhood low English proficiency	Model 6 + neighborhood inadequate plumbing
Both English and Spanish in the home						
β		2.94	2.93	2.83	3.27	2.94
95 % CI		(−3.19 to 9.08)	(−3.68 to 9.54)	(−3.71 to 9.38)	(−2.84 to 9.38)	(−3.18 to 9.05)
Building dilapidation index						
β		−0.57	−0.66	−0.59	−0.59	−0.57
95 % CI		(−1.56 to 0.43)	(−1.59 to 0.26)	(−1.52 to 0.33)	(−1.53 to 0.35)	(−1.57 to 0.44)
Neighborhood percent poverty						
β			−1.83			
95 % CI			(−4.18 to 0.53)			
Neighborhood percent < high school education						
β				**−2.02**		
95 % CI				**(−3.53 to −0.51)**		
Neighborhood percent low English proficiency						
β					**−2.69**	
95 % CI					**(−3.82 to −1.56)**	
Neighborhood percent inadequate plumbing						
β						−0.06
95 % CI						(−1.39 to 1.27)

PAH polycyclic aromatic hydrocarbons, for which high values have defined as above the median of 2.26 ng/m^3; the building dilapidation index has a range from 0 to 4 based on the number of reported problems (e.g., holes in walls, leaking pipes); neighborhood characteristics (percent poverty, percent not completing high school, percent low English language proficiency, percent inadequate plumbing) have been estimated for a 1-km network buffer surrounding the prenatal home address; each neighborhood characteristic has been rescaled to a z-score such that the coefficients shown are for a 1 standard deviation increase; all regression models account for clustering within community districts and adjust the child's sex, ethnicity, maternal education, maternal IQ score, environmental tobacco smoke exposure in the home, quality of the caretaking environment, and home English language exposure; bold face indicates statistical significance ($p < 0.05$); N = 277

Table 6

Interaction analyses of PAH exposure with neighborhood characteristics as predictors of age 5 WPSSI-R scores

	Low PAH	High PAH	Interaction *p* value
Neighborhood percent poverty			
Total score			
β	−0.39	−0.79	0.552
95 % CI	(−2.89 to 2.12)	(−3.82 to 2.24)	
Verbal			
β	1.60	0.33	0.344
95 % CI	(−0.68 to 3.88)	(1.71 to 2.36)	
Performance			
β	−2.02	−2.15	0.669
95 % CI	(−4.72 to 0.68)	(−5.87 to 1.57)	
Neighborhood percent < high school education			
Total score			
β	−1.66	−0.81	**0.014**
95 % CI	(−3.75 to 0.44)	(−2.32 to 0.70)	
Verbal			
β	0.56	0.26	0.207
95 % CI	(−1.40 to 2.52)	(−0.83 to 1.35)	
Performance			
β	**−3.16**	−1.84	**0.026**
95 % CI	**(−6.03 to −0.29)**	(−4.02 to 0.34)	
Neighborhood percent low English proficiency			
Total score			
β	**−3.23**	**−1.69**	**0.006**
95 % CI	**(−4.77 to −1.69)**	**(−2.64 to −0.73)**	
Verbal			
β	**−1.90**	**−0.51**	**0.048**
95 % CI	**(−4.36 to 0.56)**	**(−1.30 to 0.28)**	
Performance			
β	**−3.29**	**−2.52**	**0.003**
95 % CI	**(−6.97 to 0.40)**	**(−4.08 to −0.95)**	
Neighborhood percent inadequate plumbing			
Total score			
β	−0.17	0.88	0.145
95 % CI	(−2.27 to 1.93)	(−1.08 to 2.84)	
Verbal			
β	1.24	0.70	0.716
95 % CI	(−1.44 to 3.92)	(−1.55 to 2.95)	
Performance			

	Low PAH	High PAH	Interaction *p* value
β	−1.14	0.74	**0.022**
95 % CI	(−2.95 to 0.67)	(−1.36 to 2.83)	

PAH polycyclic aromatic hydrocarbons, for which high values have defined as above the median of 2.26 ng/m^3; the building dilapidation index has a range from 0 to 4 based on the number of reported problems (e.g., holes in walls, leaking pipes); neighborhood characteristics (percent poverty, percent not completing high school, percent low English language proficiency, percent inadequate plumbing) have been estimated for a 1-km network buffer surrounding the prenatal home address; each neighborhood characteristic was entered into a separate model and has been rescaled to a z-score such that the coefficients shown are for a 1 standard deviation increase; all regression models account for clustering within community districts and adjust the child's sex, ethnicity, maternal education, maternal IQ score, environmental tobacco smoke exposure in the home, quality of the caretaking environment, and home English language exposure; bold face indicates statistical significance ($p < 0.05$); N = 277