Published in final edited form as:

Laryngoscope. 2014 September ; 124(9): 2176–2181. doi:10.1002/lary.24746.

Bilateral Hearing Loss is Associated with Decreased Nonverbal Intelligence in US Children Ages 6 to 16 Years

Susan D. Emmett, MD^{1,2} and Howard W. Francis, MD, MBA¹

¹Department of Otolaryngology-Head and Neck Surgery, Johns Hopkins University School of Medicine, Baltimore, MD USA

²Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD USA

Abstract

Objectives—To evaluate the association between hearing loss and nonverbal intelligence in US children.

Study Design—The Third National Health and Nutrition Examination Survey (NHANES III) is a cross-sectional survey (1988–1994) that used complex multistage sampling design to produce nationally representative demographic and examination data.

Methods—A total of 4823 children ages 6–16 years completed audiometric evaluation and cognitive testing during NHANES III. Hearing loss was defined as low frequency pure tone average (PTA) >25 decibels (dB) (0.5, 1, 2 kHz) or high frequency PTA >25 dB (3, 4, 6, 8 kHz) and was designated as unilateral or bilateral. Nonverbal intelligence was measured using the Wechsler Intelligence Scale for Children-Revised block design subtest. Low nonverbal intelligence was defined as a standardized score <4, two standard deviations below the standardized mean of 10.

Results—Mean nonverbal intelligence scores differed between children with normal hearing (9.59) and children with bilateral (6.87; $p=0.02$) but not unilateral (9.12; $p=0.42$) hearing loss. Non-Hispanic black race/ethnicity and family income <\$20,000 were associated with 3.92 and 1.67 times higher odds of low nonverbal intelligence, respectively (OR 3.92; $p<0.001$; OR 1.67; $p=0.02$). Bilateral hearing loss was independently associated with 5.77 times increased odds of low nonverbal intelligence compared to normal hearing children (OR 5.77; $p=0.02$). Unilateral hearing loss was not associated with higher odds of low nonverbal intelligence (OR 0.73; $p=0.40$).

Conclusion—Bilateral but not unilateral hearing loss is associated with decreased nonverbal intelligence in US children. Longitudinal studies are urgently needed to better understand these associations and their potential impact on future opportunities.

Address all correspondence to: Dr. Susan D. Emmett, 601 N Caroline Street, 6th Floor, Baltimore, MD 21287, semmett2@jhmi.edu, 410-955-1932 (phone), 410.955.6526 (fax).

Financial Disclosures: none

Conflict of Interest: none

Presentation: This paper was presented at the Triological Society 2014 Combined Sections Meeting in Miami, FL on January 10, 2014

Keywords

hearing loss; nonverbal intelligence; pediatric; NHANES III

Introduction

Hearing loss affects 360 million people worldwide and has profound economic consequences.^{1,2} Adults with hearing loss are frequently unemployed or underemployed, and income of the hearing impaired has been shown to be 40–45% less than that of the general population.²

The impact of hearing loss begins early in life. In addition to the well-characterized risk of speech and language delay, children with all levels of hearing impairment may experience decreased school performance.^{3–6} Several studies have shown that children with hearing loss tend to score lower on cognitive tests than their normal hearing peers.^{4,7,8} Many of these tests do not differentiate between verbal ability and nonverbal intelligence, however, leaving unanswered whether hearing impairment strictly affects language skills or additionally impairs a child's full development of nonverbal intellect.

We sought to evaluate the association between hearing loss and nonverbal intelligence in US children ages 6–16 years using the National Health and Nutrition Examination Survey III (NHANES III). By investigating the relationship between hearing loss and nonverbal intelligence in this representative sample of US children, we seek to explore potential mechanisms by which hearing loss may inhibit the development of a child's full intellectual potential. Such findings are critical to understanding the economic impact of hearing loss and the potential social and economic benefits of various policy responses such as the identification and treatment of mild to moderate hearing loss early in life.

Materials and Methods

Study Population

The National Health and Nutrition Examination Survey (NHANES) III is a complex multistage survey conducted from 1988–1994 that provides nationally representative cross-sectional data on the health status of the civilian, non-institutionalized US population ages two months and older.⁹ The design of NHANES has been previously described.^{9,10} Briefly, after random selection through complex survey design, participants were interviewed in the home and examined in a mobile examination center. The NHANES protocol for audiometry included participants ages 6–19 years ($n = 6,166$), and the protocol for cognitive testing involved participants ages 6–16 years ($n = 5,034$).^{11,12} The present analysis is limited to individuals ages 6–16 years who completed both audiometric and cognitive evaluations ($n = 4,823$).

Audiometric Measures

Audiometric testing was completed by trained examiners in a dedicated sound-isolating room in the mobile examination center using a standardized protocol from the National

Center for Health Statistics (NCHS).¹¹ Calibration of the audiometer was performed at the start and end of testing in each field location. Air conduction thresholds were measured at 0.5, 1, 2, 3, 4, 6, and 8 kHz, with repeat testing at 1 kHz to measure reliability of participants' responses. Masking was applied if a subject's air conduction thresholds at a given frequency differed by at least 40dB between ears. The first 1 kHz threshold and masked values, when performed, were used in all analyses. Participants with cochlear implants and those using hearing aids who were unable to remove them for testing, as well as those who could not tolerate testing secondary to pain, were excluded from the audiometry component of the study.

Incorporating the World Health Organization (WHO) definition of hearing loss as PTA >25dB^{13,14} with prior investigations of NHANES III hearing data that utilize both high and low frequency PTAs,^{15,16} hearing loss was defined by a low-frequency pure tone average (PTA) >25dB (0.5, 1, 2, kHz) or a high-frequency PTA >25dB (3, 4, 6, 8 kHz). The loss was then designated as either unilateral or bilateral using mutually exclusive categories.

Cognitive Testing

Cognitive testing was conducted on eligible participants using standardized procedures.¹² Four tests were administered in a designated sequence, starting with the Wechsler Intelligence Scale for Children (WISC-R) block design and digit span subtests, followed by the Wide Range Achievement Tests (WRAT-R) reading and arithmetic subtests. Scoring was standardized according to manufacturer instructions.¹⁷ The WISC-R block design subtest evaluates nonverbal intelligence and was used for this analysis. Low nonverbal intelligence was defined as a standardized score <4, representing two standard deviations (SD = 3) below the standardized mean of 10.¹⁷

Demographic and Socioeconomic Variables

Age was categorized as 12–16 or less than 12 years. Race/ethnicity was categorized as non-Hispanic white, non-Hispanic black, or Hispanic American/other (Mexican American, other Hispanic, Asian, or Native American). The head of household was defined as the individual aged 17 or older who owns or rents the dwelling unit where the study participant lives. If no one owned or rented the unit, the head of household was defined as the first person the study participant mentioned who was at least 17 years of age. Head of household education was categorized as less than 12th grade or high school and beyond. Low family income was defined as less than \$20,000 per year.

Analysis

Sample weights were used to account for complex sampling design according to NCHS guidelines for all analyses except for Table 1.⁹ The purpose of Table 1 was to provide descriptive statistics of the study cohort instead of nationally generalizable estimates, and therefore weights were excluded. Demographic characteristics were compared by nonverbal intelligence status using the χ^2 test. Mean block scores for participants with normal hearing, unilateral hearing loss, and bilateral loss were calculated using survey mean estimation. Simple and multiple logistic regression were used to estimate the association of low nonverbal intelligence with socioeconomic factors and hearing loss. Model fit was

confirmed using the Archer and Lemeshow F-adjusted mean residual test.¹⁸ Sensitivity analyses were conducted to confirm that outliers did not influence results. The Taylor Series Linearization method for variance estimation was used per NCHS guidelines.⁹ All analyses were conducted using STATA 12.1 (StataCorp, College Station, TX). Two-sided *p* values <0.05 were considered statistically significant.

Ethics

Written consent was obtained from all participants. The NCHS Institutional Review Board approved all study protocols.

Results

A total of 6,936 individuals ages 6–16 years completed the interview for NHANES III. Of these, 5,095 went on to have audiograms during the examination component, and 5,034 underwent intelligence testing. Analysis for this study is limited to the 4,823 participants ages 6–16 years (70% of the interview sample) who underwent both audiometric and intelligence testing during the NHANES III examination.

Demographic characteristics of participants with and without low nonverbal intelligence are compared in Table 1. Race/ethnicity, education level of the head of household, and family income were associated with low nonverbal intelligence. Non-Hispanic blacks represented 58% (*n* = 234) of participants with low nonverbal intelligence and 32% (*n* = 1426) of those with normal intelligence scores (*p* < 0.001). Head of household having completed less than a high school education was associated with 54% (*n* = 217) of low nonverbal intelligence participants and 40% (*n* = 1745) of those with normal nonverbal intelligence (*p* < 0.001). Family income less than \$20,000 per year was representative of 66% (*n* = 266) of the low nonverbal intelligence group and 48% (*n* = 2109) of the normal nonverbal intelligence group (*p* < 0.001). Male sex was associated with higher nonverbal intelligence, with 50% (*n* = 2197) of the normal intelligence group being male compared to 44% (*n* = 177) of the low intelligence group (*p* = 0.03). There were similar proportions of participants with unilateral and bilateral hearing loss in both groups (*p* = 0.18).

The mean nonverbal intelligence score differed between participants with normal hearing (9.59; 95% CI: 9.39, 9.78) and those with bilateral hearing loss (6.87; 95% CI: 4.50, 9.24; *p* = 0.02). There was no difference in mean nonverbal intelligence score between normal hearing participants (9.59; 95% CI: 9.39, 9.78) and those with unilateral loss (9.12; 95% CI: 8.00, 10.24; *p* = 0.42).

Simple and multiple logistic regression analyses exploring factors associated with low nonverbal intelligence are presented in Table 2. Race/ethnicity, head of household education level, family income, and bilateral hearing loss were each associated with increased odds of low nonverbal intelligence. Non-Hispanic black participants had 4.89 times higher odds of low nonverbal intelligence compared to non-Hispanic whites (OR 4.89; 95% CI 3.37, 7.10; *p* < 0.001), and Hispanic Americans had 2.13 times increased odds of low nonverbal intelligence (OR 2.13; 95% CI 1.10, 4.13; *p* = 0.03). Head of household having less than a high school education was associated with 2.23 times higher odds of low nonverbal

intelligence (OR 2.23; 95% CI 1.55, 3.21; $p < 0.001$). Family income less than \$20,000 per year was associated with 2.68 times increased odds of low nonverbal intelligence (OR 2.68; 95% CI 1.86, 3.86; $p < 0.001$). Bilateral hearing loss was associated with a 6.94 times increased odds of low nonverbal intelligence compared to normal hearing (OR 6.94; 95% CI 1.65, 29.27; $p = 0.009$). Participants with unilateral hearing loss demonstrated the same odds of low nonverbal intelligence as those with normal hearing (OR 0.77; 95% CI 0.35, 1.70; $p = 0.50$). Male participants were marginally less likely to demonstrate low nonverbal intelligence (OR 0.66; 95% CI 0.45, 0.97; $p = 0.04$).

Results of the adjusted model are similar to the simple logistic regression analysis, with a few notable differences. After controlling for demographic and socioeconomic factors, non-Hispanic black race/ethnicity (OR 3.92; 95% CI 2.66, 5.76; $p < 0.001$), family income less than \$20,000 per year (OR 1.67; 95% CI 1.08, 2.57; $p = 0.02$), and bilateral hearing loss (OR 5.77; 95% CI 1.38, 24.07; $p = 0.02$) remained associated with low nonverbal intelligence, while Hispanic American race/ethnicity (OR 1.58; 95% CI 0.81, 3.11; $p = 0.18$), head of household education less than 12th grade (OR 1.46; 95% CI 0.92, 2.32; $p = 0.11$), and male sex (OR 0.70; 95% CI 0.48, 1.02; $p = 0.06$) lost significance. Unilateral hearing loss remained unrelated to low nonverbal intelligence in the adjusted model (OR 0.73; 95% CI 0.34, 1.54; $p = 0.40$).

Discussion

This study suggests that bilateral but not unilateral hearing loss is associated with low nonverbal intelligence in US children. These associations maintain similar magnitude and significance after controlling for important demographic and socioeconomic factors, indicating that bilateral hearing loss has an independent effect on nonverbal intelligence.

In addition to hearing loss, this study also identifies race/ethnicity and socioeconomic status as important sources of disparity in nonverbal intelligence among US children. There was a strong association between non-Hispanic black race/ethnicity and low nonverbal intelligence in this study, with the odds of low nonverbal intelligence remaining four times higher for non-Hispanic black children even after adjustment for other demographic and socioeconomic variables. Family income of less than \$20,000 per year was also associated with persistently elevated odds of low nonverbal intelligence in the adjusted model.

The relationship between lower academic performance, race, and socioeconomic status has been described in other populations,^{19–22} as well as in the NHANES III cohort itself.²³ The impact of race on academic achievement and IQ, especially the gap between black and white students, has been explored in depth.^{23–28} Our study emphasizes that this already documented achievement gap includes an increased risk of low nonverbal intelligence, especially for non-Hispanic black children and those from low income families. Possible underlying causes for these findings, including racial and socioeconomic disparities in early-life health indicators such as preterm birth and neonatal intensive care unit (NICU) admission, as well as the nature of early parent-child interactions and quality of education, need to be explored and urgently addressed.^{29–31}

There are several limitations of this study. Because the NHANES audiometric protocol included only air conduction, we were unable to differentiate between conductive and sensorineural losses. Our unilateral and bilateral categories therefore likely contain a combination of conductive, sensorineural, and mixed losses. Based on US data estimating prevalence of congenital bilateral sensorineural loss to be approximately 1–2 per 1000 live births, we estimate that up to 10 children in a population of this sample size ($n = 4800$) may have sensorineural loss.³² We found 46 cases of bilateral loss in our sample, suggesting that 75% or more may be conductive or mixed in origin. Given the differing implications of risk of low nonverbal intelligence with permanent sensorineural loss versus medically manageable conductive loss, it will be critical to include bone conduction in future studies.

All NHANES studies are cross-sectional in design and thus lack longitudinal data on participants, limiting our ability to account for early-life risk factors that may have an impact on hearing loss and cognition. Bilateral sensorineural loss is more common in infants from the NICU, especially those with syndromes or congenital anomalies, prematurity, low birth weight, exposure to ototoxic medications, history of mechanical ventilation, or low apgar scores.^{33–35} NICU survivors are simultaneously at higher risk for neurocognitive delays.³⁶ Luciana et al found 7–9 year old NICU survivors to have 25% more memory errors on nonverbal spatial working memory tasks, including poorer pattern recognition and shorter spatial memory span compared to age-matched controls.³⁷ School-aged children born with extremely low ($<1000\text{g}$) and very low ($<1500\text{g}$) birth weight have significantly lower IQs (0.5 to 1.0 SD) than their normal birth weight peers.³⁸ Children with symptomatic cytomegalovirus (CMV) infection, another major cause of nongenetic sensorineural hearing loss, similarly have a parallel risk of neurologic and cognitive deficits.^{39–41} With early-life risk factors such as low birth weight and CMV infection associated with both increased risk of hearing loss and poorer cognitive outcomes, it is critical that these potential cofounders be addressed in future studies.

There is much debate in the psychology literature regarding cultural loading and potential biases of cognitive tests, including the WISC-R.^{42,43} The effects of cultural differences and language delay on the outcome of intelligence testing cannot be ruled out. However, there is data to suggest that the nonverbal WISC-R subtests, including the block design subtest used in this analysis, are less culturally loaded and less likely to be influenced by language ability than verbal intelligence tests.^{42,44} Stark et al found that children with language delay scored significantly lower on WISC-R verbal subtests and overall IQ than their peers with normally developing language skills, but their nonverbal subtest scores were equivalent.⁴⁵ Children for whom English is not their native language, including Indian Americans and those of Latino origin, consistently score higher on nonverbal compared to verbal subtests.^{42,43}

This diminished influence of language delay on WISC-R nonverbal subtests is also seen in the deaf population. A group of 100 congenitally deaf children ($\text{PTA} > 70\text{dB}$) with deaf parents scored significantly better than deaf children with hearing parents on each of the nonverbal WISC-R subtests, including block design.⁴⁶ The deaf children with deaf parents exhibited a mean performance, or nonverbal, IQ that exceeded the national norm for hearing children, while the deaf children of hearing parents scored below this national norm. If linguistic ability was singularly influential in nonverbal subtest achievement, normal hearing

children would be expected to exceed the scores of congenitally deaf children regardless of the hearing status and communication mode of the parent. The authors suggest that the factor common to both hearing and deaf children with poorly developed nonverbal cognitive abilities may be a lack of meaningful early parent-child interactions.⁴⁶ Although none of the battery of cognitive tests is completely free of cultural or language bias, these examples support the WISC-R block design subtest as a reasonable choice for assessing nonverbal intellect in this nationally representative sample of US children.

Due to the cross-sectional nature of NHANES, there is no mechanism for studying temporality or assessing causation with the current data. Longitudinal studies will therefore be critical for further exploring the associations between bilateral hearing loss, nonverbal intelligence, and the racial and socioeconomic disparities observed in this study. Considering that NHANES III took place prior to the implementation of universal newborn hearing screening in the US, designing longitudinal studies to assess children born in the current screening environment will be vital.⁴⁷ It will be particularly important to assess efficacy of potential interventions to reverse negative associations with nonverbal intelligence, and whether these interventions differ based on type of loss. One intriguing possibility that has been suggested both in the context of socioeconomic disparities and deafness is modification of early parent-child interactions. In their landmark longitudinal study of parent-child interactions, Hart and Risley demonstrated that children's academic success and IQ are directly correlated with the amount that parents speak to their children.⁴⁸ By age three, children from low SES families heard 30 million fewer words than their high SES peers, resulting in disparities in linguistic development that continued to negatively affect academic performance at ages 9 to 10. Leffel and Suskind describe two different parent-directed interventions designed for normal hearing and hearing impaired children that seek to improve cognitive development and school readiness by directly applying Hart and Risley's findings.³¹ While the focus of these programs is on language development, there may be something inherent in the altered parent-child relationship that improves development of nonverbal intellect as well. In addition to parent-directed behavioral interventions, future studies should also evaluate the efficacy of amplification and hearing rehabilitation in reducing the association between hearing loss and low nonverbal intelligence. Such a small number of participants reported hearing aid use in NHANES III that we were unable to analyze this important question.

By evaluating the association between all levels of hearing loss and nonverbal intelligence in a representative sample of US children, our study fills an important void in the literature. Other studies examining hearing loss and cognition rely on general IQ or achievement testing without differentiating between verbal ability and nonverbal intelligence.^{3,4,6-8} It is possible that the adverse association between bilateral loss and nonverbal intelligence may contribute to poor employment outcomes seen in the hearing impaired population.^{2,3} Longitudinal studies are urgently needed to further characterize this relationship and determine whether it can be reversed with parent-directed interventions or amplification.

Conclusion

Bilateral but not unilateral hearing loss is associated with decreased nonverbal intelligence in US children ages 6–16 years. Non-Hispanic black race/ethnicity and low income are also associated with increased odds of low nonverbal intelligence in this study. Longitudinal studies investigating the relationships between hearing loss, race/ethnicity, socioeconomic status, and nonverbal intelligence are urgently needed.

Acknowledgments

This research was supported by a National Institutes of Health T32 Research Training Grant (5T32DC000027-25).

References

1. World Health Organization. [Accessed September 9, 2013] Deafness and hearing loss. <http://www.who.int/mediacentre/factsheets/fs300/en/>. Feb 2013
2. Ruben RJ. Redefining the survival of the fittest: communication disorders in the 21st century. *Laryngoscope*. 2000; 110(2 Pt 1):241–245. [PubMed: 10680923]
3. Järvelin MR, Mäki-Torkko E, Sorri MJ, Rantakallio PT. Effect of hearing impairment on educational outcomes and employment up to the age of 25 years in northern Finland. *Br J Audiol*. 1997; 31(3): 165–175. [PubMed: 9276099]
4. Bess FH, Dodd-Murphy J, Parker RA. Children with minimal sensorineural hearing loss: prevalence, educational performance, and functional status. *Ear Hear*. 1998; 19(5):339–354. [PubMed: 9796643]
5. Lieu JEC, Tye-Murray N, Fu Q. Longitudinal study of children with unilateral hearing loss. *Laryngoscope*. 2012; 122(9):2088–2095. [PubMed: 22865630]
6. Khairi Md Daud M, Noor RM, Rahman NA, Sidek DS, Mohamad A. The effect of mild hearing loss on academic performance in primary school children. *Int J Pediatr Otorhinolaryngol*. 2010; 74(1): 67–70. [PubMed: 19913305]
7. Teasdale TW, Sorensen MH. Hearing loss in relation to educational attainment and cognitive abilities: A population study. *Int J Audiol*. 2007; 46(4):172–175. [PubMed: 17454229]
8. Davis A, Hind S. The impact of hearing impairment: a global health problem. *Int J Pediatr Otorhinolaryngol*. 1999; 49(Suppl 1):S51–4. [PubMed: 10577775]
9. National Center for Health Statistics. [Accessed September 9, 2013] Analytic and Reporting Guidelines: The Third National Health and Nutrition Examination Survey, NHANES III (1988–94). Available at: <http://www.cdc.gov/nchs/data/nhanes/nhanes3/nh3gui.pdf>
10. National Center for Health Statistics. Plan and operation of the Third National Health and Nutrition Examination Survey, 1988–94. *Vital Health Stat 1*. 1994; (32):1–407.
11. [Accessed September 9, 2013] National Health and Nutrition Examination Survey III: NHANES III Audiometry and Tympanometry for Health Technicians' Manual. Available at: <http://www.cdc.gov/nchs/data/nhanes/nhanes3/cdrom/nchs/manuals/audio.pdf>
12. National Health and Nutrition Examination Survey III: NHANES III Cognitive Testing for Children. [Accessed September 9, 2013] MEC Interviewer Manual. Available at: <http://www.cdc.gov/nchs/data/nhanes/nhanes3/cdrom/nchs/manuals/cognitiv.pdf>
13. World Health Organization. [Accessed July 16, 2013] Grades of hearing impairment. Available at: http://www.who.int/pbd/deafness/hearing_impairment_grades/en/index.html
14. Agrawal Y, Platz EA, Niparko JK. Risk factors for hearing loss in US adults: data from the National Health and Nutrition Examination Survey, 1999 to 2002. *Otol Neurotol*. 2009; 30(2):139–145. [PubMed: 19092714]
15. Niskar AS, Kieszak SM, Holmes A, Esteban E, Rubin C, Brody DJ. Prevalence of hearing loss among children 6 to 19 years of age: the Third National Health and Nutrition Examination Survey. *JAMA*. 1998; 279(14):1071–1075. [PubMed: 9546565]

16. Shargorodsky J, Curhan SG, Curhan GC, Eavey R. Change in prevalence of hearing loss in US adolescents. *JAMA*. 2010; 304(7):772–778. [PubMed: 20716740]
17. Wechsler, D. Manual for the Wechsler Intelligence Scale for Children-Revised. San Antonio, TX: Psychological Corporation; 1974.
18. Archer KJ, Lemeshow S. Goodness-of-fit test for a logistic regression model fitted using survey sample data. *Stata Journal*. 2006; 6(1):97–105.
19. Felner RD, Brand S, DuBois DL, Adan AM, Mulhall PF, Evans EG. Socioeconomic disadvantage, proximal environmental experiences, and socioemotional and academic adjustment in early adolescence: investigation of a mediated effects model. *Child Dev*. 1995; 66(3):774–792. [PubMed: 7789201]
20. Davis-Kean PE. The Influence of Parent Education and Family Income on Child Achievement: The Indirect Role of Parental Expectations and the Home Environment. *Journal of Family Psychology*. 2005; 19(2):294–304. [PubMed: 15982107]
21. Sirin SR. Socioeconomic status and academic achievement: A meta-analytic review of research. *Review of educational research*. 2005; 75(3):417–453.
22. Fergusson DM, Horwood LJ, Boden JM. The transmission of social inequality: Examination of the linkages between family socioeconomic status in childhood and educational achievement in young adulthood. *Research in Social Stratification and Mobility*. 2008; 26(3):277–295.
23. Kramer RA, Allen L, Gergen PJ. Health and social characteristics and children's cognitive functioning: results from a national cohort. *Am J Public Health*. 1995; 85(3):312–318. [PubMed: 7892911]
24. Condrón DJ, Tope D, Steidl CR, Freeman KJ. Racial Segregation and the Black/White Achievement Gap, 1992 to 2009. *The Sociological Quarterly*. 2013; 54(1):130–157.
25. Downey DB. Black/white differences in school performance: The oppositional culture explanation. *Annu Rev Sociol*. 2008; 34:107–126.
26. Rothstein, R. Using social, economic, and educational reform to close the achievement gap. Washington, DC: Economic Policy Institute; 2004. Class and schools.
27. Oates G. An empirical test of five prominent explanations for the black–white academic performance gap. *Social Psychology of Education*. 2009; 12:415–41.
28. Jensen AR, Reynolds CR. Race, social class and ability patterns on the WISC-R. *Personality and Individual Differences*. 1982; 3(4):423–438.
29. de Jongh BE, Locke R, Paul DA, Hoffman M. The differential effects of maternal age, race/ethnicity and insurance on neonatal intensive care unit admission rates. *BMC Pregnancy Childbirth*. 2012; 12:97. [PubMed: 22985092]
30. Love C, David RJ, Rankin KM, Collins JW. Exploring weathering: effects of lifelong economic environment and maternal age on low birth weight, small for gestational age, preterm birth in African-American and white women. *Am J Epidemiol*. 2010; 172(2):127–134. [PubMed: 20576757]
31. Leffel K, Suskind D. Parent-directed approaches to enrich the early language environments of children living in poverty. *Semin Speech Lang*. 2013; 34(4):267–278. [PubMed: 24297619]
32. Thompson DC, McPhillips H, Davis RL, Lieu TL, Homer CJ, Helfand M. Universal newborn hearing screening: summary of evidence. *JAMA*. 2001; 286(16):2000–2010. [PubMed: 11667937]
33. Bielecki I, Horbulewicz A, Wolan T. Risk factors associated with hearing loss in infants: an analysis of 5282 referred neonates. *Int J Pediatr Otorhinolaryngol*. 2011; 75(7):925–930. [PubMed: 21571377]
34. Vohr BR, Widen JE, Cone-Wesson B, et al. Identification of neonatal hearing impairment: characteristics of infants in the neonatal intensive care unit and well-baby nursery. *Ear Hear*. 2000; 21(5):373–382. [PubMed: 11059699]
35. Korres S, Nikolopoulos TP, Komkoto V, et al. Newborn hearing screening: effectiveness, importance of high-risk factors, and characteristics of infants in the neonatal intensive care unit and well-baby nursery. *Otol Neurotol*. 2005; 26(6):1186–1190. [PubMed: 16272939]
36. Larroque B, Ancel P-Y, Marret S, et al. Neurodevelopmental disabilities and special care of 5-year-old children born before 33 weeks of gestation (the EPIPAGE study): a longitudinal cohort study. *Lancet*. 2008; 371(9615):813–820. [PubMed: 18328928]

37. Luciana M, Lindeke L, Georgieff M, Mills M, Nelson CA. Neurobehavioral evidence for working-memory deficits in school-aged children with histories of prematurity. *Dev Med Child Neurol*. 1999; 41(8):521–533. [PubMed: 10479041]
38. Stephens BE, Vohr BR. Neurodevelopmental outcome of the premature infant. *Pediatr Clin North Am*. 2009; 56(3):631–46. [PubMed: 19501696]
39. Nance WE, Lim BG, Dodson KM. Importance of congenital cytomegalovirus infections as a cause for pre-lingual hearing loss. *J Clin Virol*. 2006; 35(2):221–225. [PubMed: 16384744]
40. Foulon I, Naessens A, Foulon W, Casteels A, Gordts F. A 10-year prospective study of sensorineural hearing loss in children with congenital cytomegalovirus infection. *The Journal of Pediatrics*. 2008; 153(1):84–88. [PubMed: 18571542]
41. Elliott SP. Congenital cytomegalovirus infection: an overview. *Infect Disord Drug Targets*. 2011; 11(5):432–436. [PubMed: 21827436]
42. Reynolds, CR., Suzuki, LA. *Handbook of Psychology*. Second. John Wiley & Sons, Inc; 2012. Bias in psychological assessment: An empirical review and recommendations; p. 82-113.
43. Neisser U, Boodoo G, Bouchard TJ Jr, et al. Intelligence: knowns and unknowns. *Am Psychol*. 1996; 51(2):77–101.
44. Rose RJ, Harris EL, Christian JC, Nance WE. Genetic variance in nonverbal intelligence: data from the kinships of identical twins. *Science*. 1979; 205(4411):1153–1155. [PubMed: 572991]
45. Stark RE, Tallal P, Kallman C, Mellits ED. Cognitive abilities of language-delayed children. *J Psychol*. 1983; 114:9–19. (1st Half). [PubMed: 6864591]
46. Sisco FH, Anderson RJ. Deaf children's performance on the WISC-R relative to hearing status of parents and child-rearing experiences. *Am Ann Deaf*. 1980; 125(7):923–930. [PubMed: 7446346]
47. US Preventive Services Task Force. Universal screening for hearing loss in newborns: US Preventive Services Task Force recommendation statement. *Pediatrics*. 2008; 122(1):143–148. [PubMed: 18595997]
48. Hart, B., Risley, TR. *Meaningful Differences in the Everyday Experience of Young American Children*. Baltimore, MD: Paul H Brookes Publishing; 1995.

Table 1

Demographic characteristics of participants with and without low nonverbal intelligence, defined by a Wechsler Intelligence Scale for Children-Revised (WISC-R) standardized block design score <4.

Characteristic	Number (%) with Block Design Score:		
	Score 4 n = 4420	Score <4 n = 403	P value
Age 12–16	1682 (38)	166 (41)	0.22
Male	2197 (50)	177 (44)	0.03
Race:			<0.001
Non-Hispanic White	1228 (28)	44 (11)	
Non-Hispanic Black	1426 (32)	234 (58)	
Hispanic American or Other	1766 (40)	125 (31)	
Head of Household Education <12 th Grade	1745 (40)	217 (54)	<0.001
Family Income <\$20,000	2109 (48)	266 (66)	<0.001
Hearing Loss: *			0.18
Unilateral	146 (3)	16 (4)	
Bilateral	39 (1)	7 (2)	

* Defined as low frequency pure tone average (PTA) >25dB (0.5, 1, 2 kHz) or high frequency PTA >25dB (3, 4, 6, 8 kHz)

Table 2
Logistic regression analysis of associations of low nonverbal intelligence with socioeconomic factors and hearing loss.

Test Group	Referent	Simple			Adjusted [‡]		
		OR	95% CI	P Value	OR	95% CI	P Value
Age 12–16 years	Age <12 years	1.11	(0.81, 1.53)	0.51	1.13	(0.8, 1.52)	0.40
Male	Female	0.66	(0.45, 0.97)	0.04	0.70	(0.48, 1.02)	0.06
Race:							
Non-Hispanic Black	Non-Hispanic White	4.89	(3.37, 7.10)	<0.001	3.92	(2.66, 5.76)	<0.001
Hispanic American or Other	Non-Hispanic White	2.13	(1.10, 4.13)	0.03	1.58	(0.81, 3.11)	0.18
Head of Household Education:							
<12 th Grade	12 th Grade	2.23	(1.55, 3.21)	<0.001	1.46	(0.92, 2.32)	0.11
Family Income <\$20,000	Family Income \$20,000	2.68	(1.86, 3.86)	<0.001	1.67	(1.08, 2.57)	0.02
Hearing Loss:							
Unilateral	Normal Hearing	0.77	(0.35, 1.70)	0.50	0.73	(0.34, 1.54)	0.40
Bilateral	Normal Hearing	6.94	(1.65, 29.27)	0.009	5.77	(1.38, 24.07)	0.02

[‡] Adjusted for all variables listed in the table