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Maternal intelligence quotient (IQ) predicts IQ and language in very preterm children at age 5 years

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Abstract

Background—Sociodemographic factors are linked to cognitive outcomes in children born very preterm (VPT; 30 weeks gestation). The influence of maternal intellectual ability, a heritable trait, is unknown. Also undetermined is the extent to which associations between maternal and child intellectual ability vary according to parenting behaviors that target cognitive stimulation in the home.

Methods—At age 5 years, 84 VPT and 38 demographically matched full-term (FT) children underwent neurodevelopmental assessment. Children's intellectual ability was assessed using The Wechsler Preschool Primary Scale of Intelligence-III, and language was assessed with the Clinical Evaluation of Language Fundamentals Preschool-2. The Wechsler Test of Adult Reading estimated maternal intellectual ability. The StimQ-Preschool questionnaire provided a measure of cognitive stimulation in the home. Linear mixed-effects models examined independent effects and interactions between maternal intellectual ability and cognitive stimulation on children's outcomes.

Results—After covariate adjustment, maternal intellectual ability was associated with child intellectual ($p < .001$) and language ($p = .002$) abilities. Stronger associations were observed in FT mother-child dyads ($B = .63$, $p = .04$) than VPT dyads ($B = .42$, $p = .01$). Mothers of VPT children reported lower levels of Parental Involvement in Developmental Advance ($p = .007$) and Parental Verbal Responsiveness ($p = .04$). Group differences in Parental Involvement in Developmental Advance, but not Parental Verbal Responsivity, persisted after adjusting for social background ($p = .03$). There was no evidence of an interaction between maternal intellectual ability and Parental Involvement in Developmental Advance ($p = .34$). Instead, maternal intellectual ability ($p < .001$) and Parental Involvement in Developmental Advance ($p = .05$) independently predicted VPT children's outcomes.

Conclusions—Maternal intellectual ability is an important trait linked to VPT and FT children's intellectual and language outcomes. Prematurity increases variation in the heritability of

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intellectual ability and shifts children from the expected range based on maternal ability. Parental involvement in activities that help children master new skills may promote cognitive development in VPT children born to mothers of lower intellectual ability.

Keywords

Prematurity; intelligence; maternal factors; environmental influences; follow-up studies

Introduction

Children born very preterm (VPT; < 32 weeks gestation) are at increased risk of intellectual and language impairments compared to children born full term (FT) (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2009; Aylward, 2014). VPT children obtain, on average, standardized full scale intelligence quotient (FSIQ) scores 10 points below FT children (Kerr-Wilson, Mackay, Smith, & Pell, 2012). Language delays have been reported as early as age 24 months in VPT infants, with problems persisting to preschool and school age (Adams-Chapman, Bann, Carter, & Stoll, 2015; Barre, Morgan, Doyle, & Anderson, 2011). Importantly, VPT birth increases risks of intellectual and language impairment after accounting for sociofamilial background (Pritchard, Bora, Austin, Levin, & Woodward, 2014).

Longitudinal studies have investigated the biological and socioenvironmental mechanisms underlying developmental variation among VPT infants (Doyle et al., 2015; Feingold, 1994). Important clinical factors include gestational age, neonatal illness, and cerebral white matter abnormalities (WMA) (Anderson & Doyle, 2008; Rand, Austin, Inder, Bora, & Woodward, 2016). Preterm delivery also disproportionately occurs among socially disadvantaged mothers (Brumberg & Shah, 2015). Importantly, social adversity shapes the quality of the home environment through the limited resources and opportunities available for early learning experiences (Green et al., 2009). In a study of VPT infants ($n = 166$), a more optimal home environment, assessed using the Home Screening Questionnaire, was positively associated with early cognitive ability (Treyvaud et al., 2012). Findings persisted after adjusting for sociofamilial background, WMA, and duration of hospital stay. Wolke, Jaekel, Hall, and Baumann (2013) reported that compared to FT children, VPT children received lower parent-report Home Observation for Measurement of the Environment (HOME) Inventory index scores, which represented cumulative exposure to parental teaching, learning materials, and literacy and leisure habits at age 6 years. As both groups reported global measures of the home environment, the extent to which parents of VPT and FT children differ in specific behaviors that target cognitive stimulation in the home remains unclear.

A key background factor that is poorly understood in VPT cohorts is maternal intellectual ability. Maternal intellectual ability has direct influence on children's intellectual development because it is a genetically based and heritable trait (Kirkpatrick, McGue, Iacono, Miller, & Basu, 2014). Intellectual ability is also associated with adult life-course outcomes (Seltzer et al., 2005) that, in turn, shape the child-rearing environment (Linver, Brooks-Gunn, & Kohen, 2002). Bacharach and Baumeister (1998a) examined maternal

intelligence and quality of the home environment as predictors of intellectual ability in preterm/low birthweight infants. Findings showed that while maternal intelligence was uniquely correlated with home environment and child intelligence, there was an interaction between maternal intelligence and home environment. This suggests that the association between maternal and child intellectual ability may vary according to the level of cognitive stimulation provided in the home. This study, however, included a noncontemporaneous cohort of late preterm infants (<37 weeks gestation) who are at lower risk of impairment than VPT infants (Voigt, Pietz, Pauen, Kliegel, & Reuner, 2012).

This study examined the extent to which maternal intellectual ability (as a proxy for heritability) and cognitive stimulation provided in the home influenced intellectual and language abilities of VPT children. Specific aims were to: (a) determine if maternal intellectual ability is uniquely associated with VPT children's intellectual and language abilities after accounting for clinical (medical risk and WMA) and sociofamilial factors; (b) compare mothers of VPT and FT children on measures of cognitive stimulation provided in the home, (c) assess whether links between maternal and child abilities are explained by interactions between maternal intellectual ability and cognitive stimulation provided in the home.

Methods

Sample

The first group consisted of 104 VPT (< 30 weeks gestation) infant survivors, born during 2007–11, who were recruited from the St. Louis Children's Hospital Level-III Neonatal Intensive Care Unit. At age 5 years, 84 of 104 (81%) VPT children returned to follow-up. VPT children lost to follow-up were born to young mothers ($p = .02$) with public health insurance ($p = .002$). The second comparison group of 38 singleton FT children (37–41 weeks gestation) was recruited through two methods. Thirty children were identified from schools, pediatric offices, and local communities of VPT children at age 5. Additional children ($n = 8$) were identified as infants through a contemporaneous study at an adjoining maternity hospital. VPT and FT children were matched for age, sex, and ethnicity. Exclusion criteria included parent unable to give informed consent, infant chromosomal/congenital abnormality, and/or suspected/proven congenital infection. FT infants with acidosis on cord blood gases were also excluded. Sample characteristics are provided in Table 1.

Procedures and ethical considerations

As part of a prospective longitudinal study, VPT and FT children underwent a neurodevelopmental evaluation at age 5. Intellectual and language measures were administered by testers blind to birth status. At follow-up, mothers completed measures of intellectual ability and cognitive stimulation provided in the home. Study procedures were approved by the Washington University Human Studies Committee. Written informed consent was obtained from all caregivers.

Measures

Children's outcomes at age 5. Intellectual ability—Children's intellectual ability was assessed using the Wechsler Preschool Primary Scales of Intelligence-III (WPPSI-III; Wechsler, 2004). The subtests Information, Vocabulary, Word Reasoning, Block Design, Matrix Reasoning, and Picture Concepts were administered to obtain Full Scale IQ (FSIQ) scores as a proxy for intellectual ability. The WPPSI-III has good psychometric properties (Lichtenberger, 2005). Complete WPPSI-III data were obtained for 96.4% (81 of 84) of VPT children and all FT children. Partial data were obtained due to behavioral difficulties ($n = 1$) and parallel assessment using the Differential Abilities Scale for low-functioning children ($n = 2$) (Elliott, 2007). Intellectual delay was defined as a FSIQ < 90 and impairment defined as FSIQ < 70 (Wechsler, 2004).

Language—The Clinical Evaluation of Language Fundamentals Preschool-2 (CELF-P2) (Semel, Wiig, & Secord, 2004) assessed language ability. Together, Word Structure, Sentence Structure, and Expressive Vocabulary subtests form the Core Language Score. The CELF-P2 has excellent psychometric properties (Semel et al., 2004). Data were obtained for 92.9% (78/ of 84) of VPT children and all FT children. Missing data were attributed to behavioral problems ($n = 5$) and English not first language ($n = 1$). Language delay was defined as Core Language Score < 86 (Semel et al., 2004).

Maternal intellectual ability—Maternal intellectual ability was assessed using the Wechsler Test of Adult Reading (WTAR) (Wechsler, 2001). Participants pronounce 50 words that have atypical grapheme to phoneme translations to minimize existing word knowledge. The total raw score is then converted to demographically normed Wechsler Adult Intelligence Scales-III scores to estimate Verbal, Performance, and FSIQ scores (Wechsler, 2001). At follow-up, 85.5% (59 of 69) of mothers of VPT infants and 97.4% (37 of 38) of comparison mothers completed the WTAR. Missing data included mother familiar with the WTAR ($n = 1$), English not first language ($n = 2$), refused task ($n = 3$), interview terminated ($n = 1$), father attended interview ($n = 3$), and recording device malfunctioned ($n = 1$). Intellectual delay was defined as FSIQ < 90 (Wechsler, 2001).

Cognitive stimulation—Cognitive stimulation in the home was assessed using the 77-item StimQ-Preschool questionnaire (Dreyer, Mendelsohn, & Tamis-LeMonda, 1996), administered by an interviewer as a part of the standardized follow-up interview with the child's primary caregiver. The StimQ-Preschool is comprised of four subscales: Availability of Learning Materials (40 items; for example, puzzles), Reading (15 items; for example, books that teach concepts), Parental Involvement in Developmental Advance (15 items; for example, pointing and naming objects together), and Parental Verbal Responsivity (seven items; for example, sing-song games, conversation in a variety of contexts). The subscales consist of Yes/No response items that are summed to create total subscale scores, which together form the composite Total StimQ score. Based on the gold-standard HOME Inventory, the StimQ-Preschool has good internal reliability (Dreyer et al., 1996). Data were collected for 97% (67 of 69) caregivers of VPT children and all comparison caregivers. Missing data was attributed to poor comprehension ($n = 2$).

Other factors—To account for additional factors that have been consistently implicated in the neurodevelopment of VPT children (Anderson & Doyle, 2008; Wong & Edwards, 2013; Woodward, Anderson, Austin, Howard, & Inder, 2006), this study collected clinical and social information between birth and age 5 years. These measures included:

Infant medical risk—Clinical information for VPT infants was collected from medical records during the neonatal period. Clinical measures were dichotomized (present = 1, absent = 0) and summed to create an index score (range 0–10). Factors included: intrauterine growth restriction, prolonged oxygen supplementation, did not receive antenatal steroids, received dexamethasone, necrotizing enterocolitis, sepsis, patent ductus arteriosus, retinopathy of prematurity, ≥ 3 SD change in weight-for-height/length, and >75 th percentile for duration of parenteral nutrition.

White matter abnormality—Very preterm infants underwent MRI scan at term-equivalent postmenstrual age. MRI images were acquired on a Siemens Magnetom Trio 3T scanner using an infant-specific head coil with previously documented sequences (Smyser et al., 2013). MRI images were qualitatively scored for cystic lesions, focal signal abnormality, myelination delay, thinning of the corpus callosum, lateral ventricle dilatation and cerebral volume reduction (range 0–15) (Kidokoro, Neil, & Inder, 2013). Moderate/severe WMA was classified as a total WMA score >5 (Kidokoro et al., 2013).

Social background—Demographic information was collected between birth and age 5 for all children. Maternal characteristics were dichotomized (present = 1, absent = 0) and summed to create an index score (range 0–5). Maternal characteristics included: age ≥ 18 years at delivery, African American, no High School degree, public health insurance, and single-parent household. Socioeconomic status was estimated using income-to-needs ratio (United States Census Bureau, 2015).

Data analysis

First, birth group differences in WPPSI-III and CELF-P2 scores were examined using independent *t*-tests, Bonferroni corrected for multiple comparisons. Chi-square tests compared rates of delay between birth groups. Cohen's *d* and odds ratios provide estimates of effect size. Continuous measures were adjusted using linear mixed-effects models with mother-and-subject-within-mother entered as a random factor to account for sibling correlation, alongside sex, social risk, and income-to-needs as fixed factors. Categorical variables were adjusted using logistic regression. Analyses were rerun excluding VPT children with FSIQ <70 and with moderate/severe WMA. Mothers of VPT and FT children were compared on the WTAR using similar methods. No outliers (>3 SD) were detected on intellectual or language measures.

Second, to examine associations between maternal intellectual ability and child intellectual and language outcomes, linear mixed-effects models were fitted separately to WPPSI-III FSIQ and CELF-P2 Core Language scores. Collinearity between social risk index and maternal FSIQ scores precluded the inclusion of social risk index as a covariate. Instead, all dichotomous social background factors were considered and selected on the basis of their

association with maternal FSIQ scores. Final models included birth group, sex, birth group interaction with sex, African American mother, single-parent household, income-to-needs ratio below the poverty threshold, and maternal FSIQ scores. Mother-and-subject-within-mother was entered as a random factor to account for sibling correlation. Analysis was then confined to the VPT group with medical risk and severity of WMA included as fixed factors.

Third, birth group differences in StimQ ratings were examined using independent *t*-tests, Bonferroni corrected for multiple comparisons. Reading scale outliers (>3 *SD*, $n = 2$) were reassigned the next nonoutlier score in their respective birth group. StimQ measures were adjusted for social risk and income-to-needs.

Finally, linear mixed-effects models examined associations between prematurity, maternal FSIQ, and StimQ ratings on WPPSI-III FSIQ and CELF-P2 Core Language scores. Based on their previous significant associations, predictors included: birth group, birth group interaction with sex, single-parent household, income-to-needs ratio below the poverty threshold, and maternal FSIQ scores. Mother-and-subject-within-mother was entered as a random factor. StimQ subscales that were associated with prematurity examined main effects of cognitive stimulation. Mean-centered WTAR by StimQ interaction terms evaluated the joint effects of maternal intellectual ability and cognitive stimulation. Omega squared was calculated to estimate the variance explained by maternal FSIQ scores, StimQ ratings, and interaction variables (Xu, 2003). The significance of key findings was verified using bootstrapping with 1,000 samples and 95% confidence intervals (see Online Supplement).

Results

Birth group differences on intellectual and language measures at age 5

Very preterm children obtained Verbal, Performance, and FSIQ scores at least 1 *SD* below FT children ($p < .001$; Table 2). The magnitude of birth group differences was slightly larger for verbal subtests ($d = 0.96$) than performance subtests ($d = 0.73$). Rates of intellectual delay were greater in VPT children relative to FT children (54% vs. 11%, $p < .001$). Furthermore, 8.4% of VPT children obtained FSIQ scores in the impaired range, whereas none of the FT children were affected ($p = .07$). Covariate adjustment for sex, social risk, and income-to-needs did not alter findings ($p = .001$). Findings also persisted after excluding VPT children with intellectual impairment ($p = .002$) and moderate/severe WMA ($p = .02$).

Very preterm children also performed less well on receptive and expressive language subtests than FT children ($p < .001$; Table 2). VPT scaled scores were more than 1 *SD* below the FT group for Sentence Structure ($d = 1.03$, $p < .001$) and Word Structure ($d = 1.07$, $p < .001$). VPT children also performed less well on Expressive Vocabulary ($d = 0.80$, $p < .001$). Regarding lower Core Language Scores ($d = 1.07$, $p < .001$), VPT children were seven times more likely to be in the delayed range than FT children (37% vs. 5%, $p < .001$). Results remained unchanged after covariate adjustment ($p = .003$) and after excluding children with severe intellectual impairment ($p = .001$) and moderate/severe WMA ($p = .002$). Birth group comparisons performed with bootstrapping yielded a set of similar results (Table S1).

Maternal intellectual ability

Mothers of VPT and FT children obtained similar Verbal ($d = 0.30, p = .15$), Performance ($d = 0.27, p = .20$), and FSIQ ($d = 0.28, p = .17$) scores at follow-up (Tables S1 and S2).

Although there was a higher proportion of mothers of VPT children in the delayed range than comparison mothers (34% vs. 22%), this difference was not significant ($p = .15$). No mothers from either group were severely impaired. Results were unchanged after adjusting for social risk and income-to-needs ($p > .05$).

Predictors of children's intellectual and language outcomes at age 5

Table 3 provides a summary of the linear mixed-effects model associating maternal intellectual ability with children's intellectual and language abilities at age 5 (see Table S3, for models with bootstrapping). As expected, model estimates indicated that birth group ($p = .001$) contributed to children's lower FSIQ and Core Language scores. Sex ($p = .04$) and the birth group by sex interaction term identified VPT males at higher risk of poor intellectual outcomes ($p = .05$). Regarding social factors, a single-parent household ($p = .02$) and living below the poverty threshold ($p = .04$) were associated with children's lower FSIQ scores, while having an African American mother was not ($p = .75$). After taking these factors into account, maternal FSIQ scores were associated with both children's FSIQ and Core Language scores ($p = .002$), explaining 18.9% and 7.2% of the total variance, respectively. Within each group, maternal FSIQ scores explained 11.3% and 2.7% of the variance in FSIQ and Core Language scores of VPT children; and 16.7% and 10.1% of the variance in FSIQ and Core Language scores of in FT children, respectively.

Predictors of VPT children's intellectual and language outcomes

Linear mixed-effects models were repeated in VPT and FT groups separately. In the VPT group (Table S4), important clinical factors included an interaction between sex and severity of WMA ($p = .002$) that highlighted male VPT children with moderate/severe WMA as being most vulnerable. Single-parent household was associated with FSIQ scores ($p = .04$), whereas living below the poverty threshold was associated with Core Language Scores ($p = .03$). As in the whole group analysis, maternal FSIQ scores remained associated with FSIQ and Core Language scores in VPT children ($p = .04$). Comparisons with analysis performed in FT children (Table S5) showed that the adjusted coefficient between maternal and child FSIQ scores was higher ($B = .63, p = .04$) in FT dyads than VPT dyads ($B = .42, p = .01$), potentially suggesting greater variability among VPT dyads (Figure 1).

Cognitive stimulation in the home

Mothers of VPT children obtained lower Total StimQ scores than mothers of FT children ($d = 0.41, p = .05$; Table 4). Specifically, mothers of VPT children endorsed fewer Parental Involvement in Developmental Advance items ($d = 0.53, p = .007$) and obtained lower Parental Verbal Responsivity scores ($d = 0.46, p = .04$) than comparison mothers. No differences were found for Availability of Learning Materials ($p = .21$) or Reading ($p = .19$). Group differences in Parental Involvement in Developmental Advance persisted after adjusting for social risk and income-to-needs ($p = .03$), while differences in Parental Verbal Responsivity were attenuated ($p = .08$).

As social background did not fully explain the variance in Parental Involvement in Developmental Advance between birth groups, a supplementary linear regression was performed within the VPT group to examine predictors of reduced parental involvement. Results indicated that severity of WMA ($\beta = -.26, p = .02$) and intellectual impairment ($\beta = -.25, p = .03$), but not gestational age ($p = .06$), were important child characteristics that explained variation in Parental Involvement in Developmental Advance ($R^2 = .18, p = .002$). Birth group differences in Parental Involvement in Developmental Advance were then reanalyzed excluding four intellectually impaired VPT children with severe WMA to determine whether lower StimQ ratings in the VPT group were driven by a subset of parents with highly impaired VPT children; the results of which remained significant ($d = 0.45, p = .05$).

Maternal intellectual ability and cognitive stimulation on children's outcomes

Table 5 shows the main effects of maternal FSIQ scores, StimQ Parental Involvement in Developmental Advance and Parental Verbal Responsivity ratings, as well as mean-centered interaction terms estimating the joint effects of maternal FSIQ and StimQ subscales. After accounting for risks associated with being born VPT and male ($p < .001$), children who were living in a single-parent household ($p = .04$) below the poverty threshold ($p = .05$) were more likely to have lower FSIQ scores at age 5 years. As expected, maternal FSIQ scores ($p < .001$) continued to make a unique contribution to the model and explained 14.3% of the variance. After accounting for maternal FSIQ, StimQ Parental Involvement in Developmental Advance ratings were independently and positively associated with child IQ ($p = .05$), explaining 10.5% of the variance.

In contrast to the hypothesis, interaction terms between maternal FSIQ scores and StimQ Parental Involvement in Developmental Advance ($p = .34$) and StimQ Parental Verbal Responsivity ($p = .99$) ratings were not statistically significant, explaining only 3.7% of variance in children's FSIQ scores. The only significant predictors of children's Core Language scores were the birth group by sex interaction term ($p = .005$) and maternal FSIQ scores ($p < .001$).

Discussion

This study examined maternal intellectual ability (as a proxy for heritability) as an important predictor of VPT children's intellectual and language abilities at age 5. We also examined the extent to which maternal intellectual ability interacted with cognitive stimulation provided in the home environment.

Maternal FSIQ scores were positively related to VPT children's FSIQ and language scores at age 5. Similar to Bacharach and Baumeister (1998b) and Tong, Baghurst, Vimpani, and McMichael (2007), maternal intellectual ability had a unique association with children's outcomes. Specifically, after accounting for a child being raised in a single-parent household and below the poverty threshold, maternal intellectual ability explained 19% and 7% of variance in children's intellectual and language abilities, respectively. Additional risk factors included being born male with moderate/severe WMA (Rose et al., 2009). Although maternal education has been linked with child outcomes (Wong & Edwards, 2013),

education is used as a proxy for intellectual ability (Voss, Jungmann, Wachtendorf, & Neubauer, 2012). Moreover, intellectual ability reflects the integration of heritable and learned capacities and is a stronger predictor of parenting behavior than parental education (Der, Batty, & Deary, 2006; Green et al., 2009).

Model estimates and the proportion of variance that was explained by maternal FSIQ scores suggested that maternal and child FSIQ associations were stronger in FT dyads than VPT dyads. Weaker associations among VPT dyads might indicate greater variability such that VPT birth shifts children from the expected heritable IQ range based on maternal ability. Heritability studies suggest that family background determines the reaction range for heritable and continuously distributed traits but that neurodevelopmental disorders increase phenotypic variability in these traits during childhood (Finucane, Challman, Martin, & Ledbetter, 2016; Moreno-De-Luca et al., 2015). VPT children born to low IQ mothers may therefore be at higher risk of poor outcomes.

At age 5, VPT children were being raised in households characterized by lower levels of cognitive stimulation than demographically matched FT children. Although a small number of studies lack a comparable FT group (Feingold, 1994; Treyvaud et al., 2012; Weisglas-Kuperus, Baerts, Smrkovsky, & Sauer, 1993), Wolke et al. (2013) also found reduced cognitive stimulation in the home for VPT children compared to FT children. Furthermore, our findings specifically showed that parents of VPT children were less involved in learning and play activities that support children's mastery of new skills and had fewer verbal interactions in daily situations. These findings are consistent with observational studies reporting that parents of VPT children are less likely to scaffold and are less responsive children than parents of FT children (Erickson et al., 2013; Jaekel, Wolke, & Chernova, 2012).

Importantly, birth group differences in parental involvement persisted after adjusting for sociofamilial factors associated with parenting behavior (Trentacosta et al., 2008). Furthermore, the characteristics of VPT children that were linked to reduced parental involvement included severity of WMA and intellectual impairment. This could indicate that higher risk VPT children are more likely to be raised in less optimal home environments. It is also possible that the complex neurodevelopmental consequences of preterm birth affects a parent's ability to provide age-appropriate learning experiences, or influences the expectations that parents have regarding their child's developmental ability (see Jaekel et al., 2012). However, after excluding a subset of severely compromised VPT children, lower parental involvement ratings persisted among VPT children. Group differences in parental verbal responsivity were explained by family background, suggesting that context is important for the social-communicative components of parenting (Landry, Smith, & Swank, 2006).

In contrast to the hypothesis, there was no interaction between maternal FSIQ scores and StimQ ratings on children's FSIQ and Core Language scores at age 5, suggesting that the effect of maternal intellectual ability did not vary by the level of cognitive stimulation provided in the home. Instead, there was evidence for unique and positive effects of maternal intellectual ability and parental involvement, with these factors uniquely explaining 14% and

11% of the variance in child intellectual ability, respectively. In late preterm children, Bacharach and Baumeister (1998b) found that maternal IQ had a direct effect on children's IQ. In contrast, Brooks-Gunn, Klebanov, and Duncan (1996) found that mother and child IQ associations were fully explained by the quality of the home environment (see also Ronfani et al., 2015). These previous studies employed hierarchical regression analyses with diverse sets of explanatory variables which might account for the discrepancy in results. Nonetheless, studies of nonpreterm cohorts also report unique and/or direct effects of maternal IQ and home environment on children's intellectual ability (Luster & Dubow, 1992; Tong et al., 2007), highlighting multiple contextual factors on neurodevelopmental outcomes.

Finally, while maternal intellectual ability predicted children's language outcomes, measures of cognitive stimulation did not. This was unexpected given that Cates et al. (2012) found that StimQ-Infant subscales were directly related to infant communication at age 6 months and indirectly related to language at age 24 months in low-income American families. Differences in findings may be explained by timing of assessment such that maternal IQ and the home environment vary in their saliency as predictors over time (Aylward, 1992; Yeates, MacPhee, Campbell, & Ramey, 1983). Luster and Dubow (1992) found that maternal IQ and home environment had comparable influences on children's verbal ability at preschool age, whereas maternal IQ had a stronger influence at school age. At early school age, other factors such as the time spent in school and the quality of school environment may also be important determinants of language ability (Aikens & Barbarin, 2008; Melhuish et al., 2008).

Study strengths included a high rate of sample retention (>80%) in an urban, high-risk cohort of VPT children; a demographically matched comparison sample; and standardized measures of intellectual and language ability. Importantly, this is the first VPT study to assess maternal intellectual ability. Although our rate of African American families is comparable to other urban American samples (Hack et al., 2005), our findings may not be generalizable to European and Australian samples with fewer ethnic minority families (Anderson & Doyle, 2003; Costeloe, Hennessy, Gibson, Marlow, & Wilkinson, 2000). Limitations also include modest sample size ($n = 122$) and the fact that although the StimQ-Preschool was developed using the gold-standard HOME Inventory (Dreyer et al., 1996), cognitive stimulation was primarily assessed using parent-report. Future studies should complement the StimQ-Preschool with observational ratings from parent-child interaction tasks (see Bennetts, Mensah, Westrupp, Hackworth, & Reilly, 2016). This study also used a brief assessment of maternal intellectual ability. However, the WTAR was selected to balance participant burden and because it yields demographically normed FSIQ scores that correlate well with comprehensive test batteries (Strauss, Sherman, & Spreen, 2006). Finally, as paternal intellectual ability was not assessed, the extent to which VPT children's outcomes are influenced by biparental FSIQ remains unclear. Thus, future preterm studies should collect paternal FSIQ, and recruit FT siblings of VPT subjects to quantify FSIQ shifts relative to siblings raised in the same environment.

Conclusion

Maternal intellectual ability is an important predictor of neurodevelopment in both VPT and FT children. Maternal intellectual ability accounted for a greater proportion of variance in FT children's outcomes than VPT children, suggesting that prematurity increases the phenotypic variability in intellectual ability between mothers and children. However, even in the setting of genetic liability, parental involvement in activities that help children master new concepts and skills is a potentially modifiable factor that could alter pathways from preterm birth to adverse cognitive outcomes. Mothers of higher risk VPT infants, such as those with moderate/severe WMA and early cognitive delay, may need additional supports to implement developmentally appropriate parenting techniques. Information highlighting the important role that parenting has on child development should be communicated to parents in ways that are clear and comprehensible to mothers of all intellectual abilities.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Key points

- Sociodemographic adversity increases risks of intellectual and language delay in VPT children.
- The influence of maternal intellectual ability, and its interaction with cognitive stimulation in the home, is undetermined.
- Maternal intellectual ability and cognitive stimulation were uniquely associated with VPT children's intellectual outcomes after accounting for family structure and poverty.
- Parental involvement in developmental advance may be a modifiable environmental factor that supports cognitive development in the preterm infant.
- Information highlighting the role of parental involvement should be communicated to mothers in ways that is clear and comprehensible to mothers of all intellectual abilities.

Figure 1.

Distributions of Full Scale IQ Scores for Mothers and Children. Figure 1 shows the Full Scale IQ score distributions for mothers (panel A) and their very preterm children (panel B); and mothers (panel C) and their full-term children (panel D). Mother-Child deviations in Full Scale IQ scores were greater in very preterm dyads ($d = 0.67$, $p < .001$) than full-term dyads ($d = 0.51$, $p = .03$), suggesting prematurity shifts children more than half a standard deviation below their mothers

Table 1
Characteristics of the sample

	VPT (<i>n</i> = 84)	FT (<i>n</i> = 38)	<i>p</i>
Clinical characteristics, %			
Gestational age (weeks), <i>m</i> (<i>SD</i>)	26.52 (1.8)	39.55 (0.8)	<.001
Birthweight (grams), <i>m</i> (<i>SD</i>)	933.12 (255.8)	3423.08 (517.0)	<.001
Male	44.0	44.7	.94
Multiple birth	33.3	—	
Antenatal steroids not administered	8.3	—	
Postnatal dexamethasone administered	10.7	—	
Sepsis	32.1	—	
Necrotizing enterocolitis	6.0	—	
Prolonged oxygen supplementation	53.6	—	
Patent ductus arteriosus	39.3	—	
Retinopathy of prematurity	16.7	—	
Neonatal brain injury, % ^{<i>a</i>}			
Periventricular leukomalacia grade III/IV	2.6	—	
Intraventricular hemorrhage grade III/IV	6.6	—	
Moderate/severe white matter abnormality ^{<i>b</i>}	38.2	—	
Social background, %			
African American	39.3	39.5	.98
Mother 18 years at delivery	4.8	2.6	.50
Mother not a High School graduate	4.8	2.6	.50
Single-parent household	46.4	36.8	.22
Income-to-needs ratio, <i>m</i> (<i>SD</i>)	1.93 (2.0)	2.30 (2.2)	.37
Social risk index, <i>m</i> (<i>SD</i>)	1.55 (1.4)	1.24 (1.3)	.24

FT, full term; VPT, very preterm.

^{*a*}From term-equivalent MRI (*n* = 76).

^{*b*}Kidokoro et al. (2013).

Table 2
Intellectual and language abilities of very preterm and full-term children

	VPT (<i>n</i> = 84)	FT (<i>n</i> = 38)	<i>d</i> /OR	<i>p</i>	Adjusted <i>p</i> ^{<i>a</i>}
WPPSI-III, <i>m</i> (<i>SD</i>)					
Verbal IQ ^{<i>b</i>}	89.40 (14.8)	107.13 (15.9)	1.15	<.001 <i>c,d</i>	<.001
Information	8.20 (3.0)	11.03 (2.9)	0.96	<.001 <i>c,d</i>	<.001
Vocabulary	7.94 (3.0)	10.92 (2.8)	1.03	<.001 <i>c,d</i>	<.001
Word reasoning	8.46 (3.3)	11.87 (3.0)	1.08	<.001 <i>c,d</i>	<.001
Performance IQ	91.20 (15.2)	108.05 (16.8)	1.05	<.001 <i>c,d</i>	<.001
Block design	8.59 (3.6)	11.13 (3.4)	0.73	.001 <i>c,d</i>	.001
Matrix reasoning	8.58 (2.8)	11.53 (3.6)	0.91	<.001 <i>c,d</i>	<.001
Picture concepts	8.95 (2.4)	11.45 (3.0)	0.92	<.001 <i>c,d</i>	<.001
Full Scale IQ	88.20 (14.3)	108.03 (16.0)	1.31	<.001 <i>c,d</i>	<.001
Intellectual delay, %	54.2	10.5	10.06	<.001 <i>c,d</i>	<.001
CELF-P2, <i>m</i> (<i>SD</i>) ^{<i>e</i>}					
Core language score	88.50 (17.7)	105.47 (13.7)	1.07	<.001 <i>c,d</i>	<.001
Sentence structure	7.82 (3.4)	10.84 (2.4)	1.03	<.001 <i>c,d</i>	<.001
Word structure	8.14 (3.9)	11.55 (2.7)	1.07	<.001 <i>c,d</i>	<.001
Expressive Vocabulary	8.09 (2.8)	10.42 (3.0)	0.80	<.001 <i>c,d</i>	<.001
Language delay, %	37.2	5.3	10.65	<.001 <i>c,d</i>	.003

CELF-P2, Clinical Evaluation of Language Fundamentals Preschool-2; FSIQ, full scale intelligence quotient; FT, full term; VPT, very preterm; WMA, white matter abnormalities; WPPSI-III, Wechsler Preschool Primary Scales of Intelligence.

Bonferroni corrected *p*-value $\alpha = .05/15$ comparisons: $p < .003$.

^{*a*} Adjusted for sibling correlation, sex, social risk, and income-to-needs.

^{*b*} VPT $n = 81$ for Verbal IQ measures.

^{*c*} $p = .002$ excluding 7 VPT children with FSIQ < 70.

^{*d*} $p = .02$ excluding 29 VPT with moderate/severe WMA.

$V_{PT} n = 78$ for CELF-P2 measures.

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Table 3
Association between maternal intellectual ability and children's intellectual and language abilities

Fixed factors	Intellectual ability (<i>n</i> = 108)		Language ability (<i>n</i> = 106)	
	Coefficient (SE)	<i>p</i>	Coefficient (SE)	<i>p</i>
Intercept	38.75 (13.3)	.004	38.64 (15.4)	.01
Birth group	12.35 (3.4)	.001	9.94 (3.9)	.01
Sex	−5.90 (2.8)	.04	−4.53 (2.7)	.10
Birth group: interaction with sex	9.86 (5.0)	.05	7.91 (5.4)	.15
Mother African American	−1.14 (3.6)	.75	2.52 (4.2)	.55
Single-parent household	8.09 (3.5)	.02	4.32 (4.2)	.31
Income-to-needs	−6.84 (3.3)	.04	−7.06 (3.9)	.08
Maternal FSIQ scores	0.56 (0.2)	<.001	0.57 (0.2)	.002

FSIQ, full scale intelligence quotient.

Table 4

Levels of cognitive stimulation provided in the home, *m* (*SD*)

StimQ scaled scores, <i>m</i> (<i>SD</i>)	VPT (<i>n</i> = 67)	FT (<i>n</i> = 38)	<i>d</i>	<i>p</i>	Adjusted <i>p</i> ^{<i>a</i>}
Total StimQ	42.79 (5.1)	44.74 (4.4)	0.41	.05	.15
Availability of learning materials ^{<i>b</i>}	30.88 (6.1)	32.47 (6.5)	0.25	.21	.65
Reading	16.60 (2.9)	17.32 (2.3)	0.28	.19	.48
Parental involvement in developmental advance	12.79 (1.9)	13.66 (1.3)	0.53	.007	.03
Parental verbal responsiveness	5.71 (1.3)	6.21 (0.8)	0.46	.04	.08

FT, full term; VPT, very preterm.
Bonferroni corrected *p*-value $\alpha = .05/5$ comparisons: $p < .01$.

^{*a*} Adjusted for social risk and income-to-needs.

^{*b*} Raw score reported due to severe ceiling effect in scaled score.

Table 5
Summary of associations between maternal IQ, cognitive stimulation, and children's intellectual and language abilities

Factor	Intellectual ability (<i>n</i> = 108)		Language ability (<i>n</i> = 107)	
	Coefficient (<i>SE</i>)	<i>p</i>	Coefficient (<i>SE</i>)	<i>p</i>
Intercept	22.39 (14.4)	.12	22.67 (17.2)	.19
Birth group: interaction with sex	15.56 (3.7)	<.001	12.12 (4.2)	.005
Single-parent household	7.51 (3.7)	.04	3.87 (4.5)	.39
Income-to-needs	-8.26 (4.1)	.05	-6.11 (5.0)	.22
Maternal FSIQ scores	0.56 (0.1)	<.001	0.60 (0.2)	<.001
StimQ PIDA	1.62 (0.8)	.05	1.10 (1.0)	.26
StimQ PVR	-0.85 (1.2)	.47	-0.04 (1.4)	.98
Maternal FSIQ scores: interaction with StimQ PIDA	0.06 (0.7)	.34	-0.03 (0.1)	.70
Maternal FSIQ scores: interaction with StimQ PVR	-0.01 (0.1)	.99	0.06 (0.1)	.57

FSIQ, full scale intelligence quotient; PIDA, Parental Involvement in Developmental Advance; PVR, Parental Verbal Responsivity.