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Identification of Modifiable Social and Behavioral Factors Associated With Childhood Cognitive Performance

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Supplemental content

IMPORTANCE Inequities in social environments are likely associated with a large portion of racial disparities in childhood cognitive performance. Identification of the specific exposures associated with cognitive development is needed to inform prevention efforts.

OBJECTIVE To identify modifiable factors associated with childhood cognitive performance.

DESIGN, SETTING, AND PARTICIPANTS This longitudinal pregnancy cohort study included 1503 mother-child dyads who were enrolled in the University of Tennessee Health Science Center–Conditions Affecting Neurodevelopment and Learning in Early Life study between December 1, 2006, and July 31, 2011, and assessed annually until the children were aged 4 to 6 years. The analytic sample comprised 1055 mother-child dyads. A total of 155 prenatal, perinatal, and postnatal exposures were included to evaluate environment-wide associations. Participants comprised a community-based sample of pregnant women who were recruited between 16 weeks and 28 weeks of gestation from 4 hospitals in Shelby County, Tennessee. Women with high-risk pregnancies were excluded. Data were analyzed from June 1, 2018, to April 15, 2019.

EXPOSURES Individual and neighborhood socioeconomic position, family structure, maternal mental health, nutrition, delivery complications, birth outcomes, and parenting behaviors.

MAIN OUTCOMES AND MEASURES Child's full-scale IQ measured by the Stanford-Binet Intelligence Scales, Fifth Edition, at age 4 to 6 years.

RESULTS Of 1055 children included in the analytic sample, 532 (50.4%) were female. Among mothers, the mean (SD) age was 26.0 (5.6) years; 676 mothers (64.1%) were Black, and 623 mothers (59.0%) had an educational level of high school or less. Twenty-four factors were retained in the least absolute shrinkage and selection operator regression analysis and full models adjusted for potential confounding. Associations were noted between child cognitive performance and parental education and breastfeeding; for each increase of 1.0 SD in exposure, positive associations were found with cognitive growth fostering from observed parent-child interactions (β = 1.12; 95% CI, 0.24-2.00) and maternal reading ability (β = 1.42; 95% CI, 0.16-2.68), and negative associations were found with parenting stress (β = −1.04; 95% CI, −1.86 to −0.21). A moderate increase in these beneficial exposures was associated with a notable improvement in estimated cognitive test scores using marginal means (0.5% of an SD). Black children experienced fewer beneficial cognitive performance exposures; in a model including all 24 exposures and covariates, no racial disparity was observed in cognitive performance (95% CIs for race included the null).

CONCLUSIONS AND RELEVANCE The prospective analysis identified multiple beneficial and modifiable cognitive performance exposures that were associated with mean differences in cognitive performance by race. The findings from this observational study may help guide experimental studies focused on reducing racial disparities in childhood cognitive performance.

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Childhood cognitive performance is associated with future mortality and morbidity across a number of conditions, including heart disease, cancer, and anxiety disorders.[1-3] Although once considered a primarily inherited characteristic, childhood cognitive performance has been reported to be sensitive to environmental conditions in multiple studies.[4-7] This sensitivity is especially relevant among children growing up in households with low socioeconomic conditions, in which environmental circumstances account for a larger proportion of the variance in childhood cognitive function than do genetic predispositions.[8-10] The preponderance of data suggests that early environmental exposures are important for early cognitive development.

Children develop in complex learning environments that are characterized by myriad social, physical, and chemical exposures, many of which have been associated with cognitive performance and are distributed inequitably by race and socioeconomic position.[11,12] Exposures include those modifiable by prevention and intervention efforts, such as prenatal and postnatal exposure to environmental toxins[13-15]; prenatal and postnatal nutrition[16,17]; parental educational level and household income[18]; smoking during pregnancy[18]; breastfeeding, birth weight, and maternal body mass index during pregnancy[19]; exposure to domestic violence[20]; and parenting behaviors.[21] However, these exposures are often examined independently, reflecting disciplinary perspectives. Concurrent testing of multiple aspects of the early environment may reveal targets for intervention that are most likely to be associated with reductions in cognitive performance disparities.

We used an environment-wide association approach[22,23] to examine 155 factors associated with childhood cognitive performance in a prospective pregnancy cohort study of mother-child dyads living in an urban area in the southern US. Measurements included detailed multilevel and multimodal phenotyping in the prenatal and postnatal periods; the examined variables encompassed individual and neighborhood measures of socioeconomic position, family structure, maternal mental health, nutrition, birth outcomes, and observed and self-reported measures of parenting behaviors.[24] Our goal was to identify modifiable exposures that may be targeted in future interventions designed to achieve equity in early learning environments for all children.

Key Points

Question Are specific exposures associated with childhood cognitive performance and are inequities in these exposures associated with racial disparities in cognitive test scores?

Findings In this cohort study of 1055 mother-child dyads, 24 of 155 prenatal and postnatal exposures were associated with childhood cognitive performance; models that included all of the exposures fully accounted for the racial disparities in cognitive test scores. Modifiable exposures included breastfeeding, parental educational levels, fostering of cognitive growth during mother-child interactions, parenting stress, and maternal reading ability, which together were associated with 0.5% of a standard deviation difference in cognitive test scores.

Meaning The study's results indicated that addressing inequities in the early environment could help to reduce racial disparities in childhood cognitive performance.

Methods

The Conditions Affecting Neurodevelopment and Learning in Early Life (CANDLE) study conducted through the University of Tennessee Health Sciences Center is a prospective pregnancy cohort study in Shelby County, Tennessee, that was originally initiated to identify early-life factors of neurocognitive development. From December 1, 2006, to July 31, 2011, the CANDLE study enrolled 1503 pregnant women between 16 weeks and 28 weeks of gestation who were planning to deliver at 1 of 4 participating hospitals. Women with known chronic conditions (eg, hypertension and diabetes) were excluded. Extensive longitudinal data collection included clinical visits conducted twice during pregnancy and at annual intervals throughout childhood.[24] The analytic sample included all children with a recorded full-scale IQ measurement from the visit conducted at age 4 to 6 years. All research activities were approved by the institutional review board of the University of Tennessee Health Sciences Center, and written informed consent was obtained from all mothers. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline for cohort studies.

Based on previous literature and theory,[4-20] we evaluated the full CANDLE data set to identify factors that may be associated with childhood cognitive performance. We excluded measures of the same construct that had high Spearman correlation coefficients (defined as >0.85); if subscale scores and overall scores had high correlation coefficients, only overall scores were included. We also calculated the mean of the same measure at multiple points, keeping prenatal and postnatal measurements separate if they did not have high correlation coefficients. Continuous variables were standardized to a mean of 0 and an SD of 1.0 for all analyses. In the first stage of analysis, indicator variables were created from categorical variables, with indicators assigned a value of −1.0 or 1.0, and the reference group included all other categories. This approach allowed us to examine each category as a separate exposure. In stages 2 and 3, all categories of an exposure selected in stage 1 were included in the final models. Our analysis included multiple distinct measures of the following multilevel broad domains of exposure measured across the prenatal and postnatal periods: socioeconomic position; family structure; maternal cognition, mental health, physical health, and stress; mother and infant nutrition; labor and delivery complications; birth outcomes; infant and child health; parenting behaviors; enrollment in supplementary programs (eg, the Women, Infants, and Children program); and maternal perceptions of neighborhood quality.

A total of 161 variables were identified through this process described in eTable 1 in the Supplement). From these variables, we identified a minimal set of a priori–defined confounding variables to include in all models that (1) may have been associated with cognitive performance, (2) were present at the time of child's birth, or (3) captured important study design outcomes. These covariates comprised child's age at assessment, child's year of birth, maternal cognitive performance on the Wechsler Abbreviated Scales of Intelligence,[25] child's sex, and paternal and maternal ages at child's birth. The remaining 155 variables were considered target exposures in our analyses.

Each child's standardized full-scale IQ was assessed by trained psychologists using the Stanford-Binet Intelligence Scales, Fifth Edition (the mean [SD] score for the test is 100 [15] points, with higher scores indicating higher cognitive performance), which has been validated and normed in large diverse populations and includes tasks that assess working memory, processing speed, visual-spatial skills, vocabulary, and language comprehension.[26]

Statistical Analysis

The analysis occurred in 3 stages. During stage 1, we selected those exposures (from the 155 total exposures) that were associated with cognitive performance, adjusting for the a priori–selected covariates that were identified as potential confounding variables. Thus, using 155 independent multivariable regression models (which were adjusted for the child's age and sex, maternal and paternal ages at the child's birth, and maternal cognitive performance), we estimated associations between each target exposure and the child's cognitive performance. Target exposures were considered statistically significant at $P = .05$ after multiple-comparison adjustment for the false discovery rate.[27,28]

In stage 2, we applied the least absolute shrinkage and selection operator (LASSO) method to a model that included all target exposures that had a statistically significant association with the outcome after correction for false discovery rate. The LASSO method decreases unstable effect estimates toward 0 and excludes colinear covariates.[29-31]

In stage 3, factors retained in the LASSO regression model were incorporated into multiple parsimonious models to evaluate associations with adjustment for potential confounding variables of the specific exposures associated with cognitive performance that were being examined. For example, the final models for target exposures did not include variables that occurred after the target exposure (eg, no postnatal covariates were included in models of prenatal exposures).

We evaluated the distributions of exposures retained in stage 3 by race (White vs Black or other race). We also calculated the proportion of the mean difference in cognitive test scores by race through inclusion of these exposures plus covariates in a single fully adjusted model.

We used the missForrest package in R software (R Foundation for Statistical Computing) to impute the values of missing indicator and control variables in the analytic sample. This method does not rely on distributional assumptions, accommodates nonlinear associations and interactions,[32] and outperforms or is similar to multivariate imputation by chained equations for contexts in which many exposures are examined.[33]

Global Chow tests[34] were used to examine whether the final models from stage 3 differed by household income (dichotomized at <50% of the median of disposable income for the US in 2010, or $14 550)[35] and child sex or race. If the results of the global Chow test were statistically significant, we performed fully interactive models using the modifier of interest.[36] All data were analyzed from June 1, 2018, to April 15, 2019.

Results

Of 1503 participants enrolled, 11 fetuses and 5 children died; 71 participants withdrew from the study, and 260 participants did not attend the visit at age 4 to 6 years. Among those who attended the visit, 101 participants did not have a completed outcome measure. The analytic sample included 1055 mother-child dyads with cognitive test scores recorded at age 4 to 6 years (mean [SD] score, 99.8 [14.9] points) (**Table 1**). Among mothers in the analytic sample, the mean (SD) age was 26.0 (5.6) years; 676 mothers (64.1%) were Black, 311 mothers (29.5%) were White, and 68 mothers (6.4%) were of another race (most of whom were of multiple races and identified as Black). A total of 623 mothers (59.0%) had an educational level of high school or less. A total of 630 mothers (59.7%) had Medicaid or TennCare insurance, and 440 mothers (41.7%) had household incomes of less than $25 000. Among children in the analytic sample, the mean (SD) age was 4.4 (0.5) years, and 532 children (50.4%) were female. A comparison of participants included in the analytic sample with those excluded from the analysis indicated that the samples had similar demographic characteristics. Compared with participants excluded from the analytic sample, mothers included in the analysis were slightly older (mean [SD] age, 25.3 [5.1] years vs 26.0 [5.6] years, respectively) and more children were born in 2009 or later (72.5% vs 60.8%, respectively). Descriptive data on all variables are available in eTable 1 in the Supplement.

We identified 29 exposures that were associated with cognitive test scores after correcting for false discovery rate (**Figure**). These exposures spanned multiple domains and comprised both modifiable and nonmodifiable characteristics, including family structure (previous pregnancies, first birth order, and adult-to-child ratio); maternal psychosocial factors (social support, social ties in their neighborhood, and parenting stress); neighborhood characteristics (maternal perceptions of neighborhood quality, mean total score on the Child Opportunity Index [score range, 1-100, with higher scores indicating more childhood opportunity at the neighborhood level], and score on the education domain of the Child Opportunity Index [measured in quintiles, with higher quintiles indicating more opportunity]); socioeconomic characteristics (maternal and paternal educational levels; income adjusted for household size; enrollment in the Women, Infants, and Children program and reduced-price meal programs; receipt of food stamps; and health insurance status); parenting behaviors and cognitive enrichment (parental involvement [measured using the Parenting Relationship Questionnaire], child abuse poten-

Table 1. Characteristics of Participants Included in and Excluded From the Analytic Sample

Characteristic	No. (%)	
	Included in analytic sample (n = 1055)	Excluded from analytic sample (n = 448)
Child's sex		
Male	523 (49.6)	213 (47.5)
Female	532 (50.4)	194 (43.3)
Missing	0	41 (9.2)
Birth year		
2007	85 (8.1)	51 (11.4)
2008	205 (19.4)	87 (19.4)
2009	248 (23.5)	84 (18.7)
2010	296 (28.1)	85 (19.0)
2011	221 (20.9)	103 (23.0)
Missing	0	38 (8.5)
Mother's age, mean (SD)	26.0 (5.6)	25.3 (5.1)
Missing	0	0
Father's age, mean (SD)	28.0 (6.8)	29.0 (6.4)
Missing	27.0 (2.6)	11.0 (2.5)
Race		
Black	676 (64.1)	260 (58.0)
White	311 (29.5)	156 (34.8)
Other	68 (6.4)	30 (6.7)
Missing	0	2 (0.5)
Mother's educational level		
≤High school	623 (59.0)	270 (60.3)
Technical school	100 (9.5)	38 (8.5)
College	209 (19.8)	90 (20.1)
Graduate school	122 (11.6)	49 (10.9)
Missing	1 (0.1)	1 (0.2)
Health insurance status		
No insurance	2 (0.2)	0
Medicaid	594 (56.3)	265 (59.2)
Medicaid and private insurance	36 (3.4)	6 (1.3)
Private insurance	423 (40.1)	177 (39.5)
Missing	0	0
Household income, $		
≤4999	136 (12.9)	55 (12.3)
5000-9999	78 (7.4)	27 (6.0)
10 000-14 999	70 (6.6)	27 (6.0)
15 000-19 999	74 (7.0)	26 (5.8)
20 000-24 999	82 (7.8)	24 (5.4)
25 000-34 999	109 (10.3)	46 (10.3)
35 000-44 999	63 (6.0)	46 (10.3)
45 000-54 999	80 (7.6)	26 (5.8)
55 000-64 999	56 (5.3)	24 (5.3)
65 000-74 999	60 (5.7)	25 (5.6)
≥75 000	165 (15.6)	69 (15.4)
Missing	82 (7.8)	53 (11.8)

(continued)

Table 1. Characteristics of Participants Included in and Excluded From the Analytic Sample (continued)

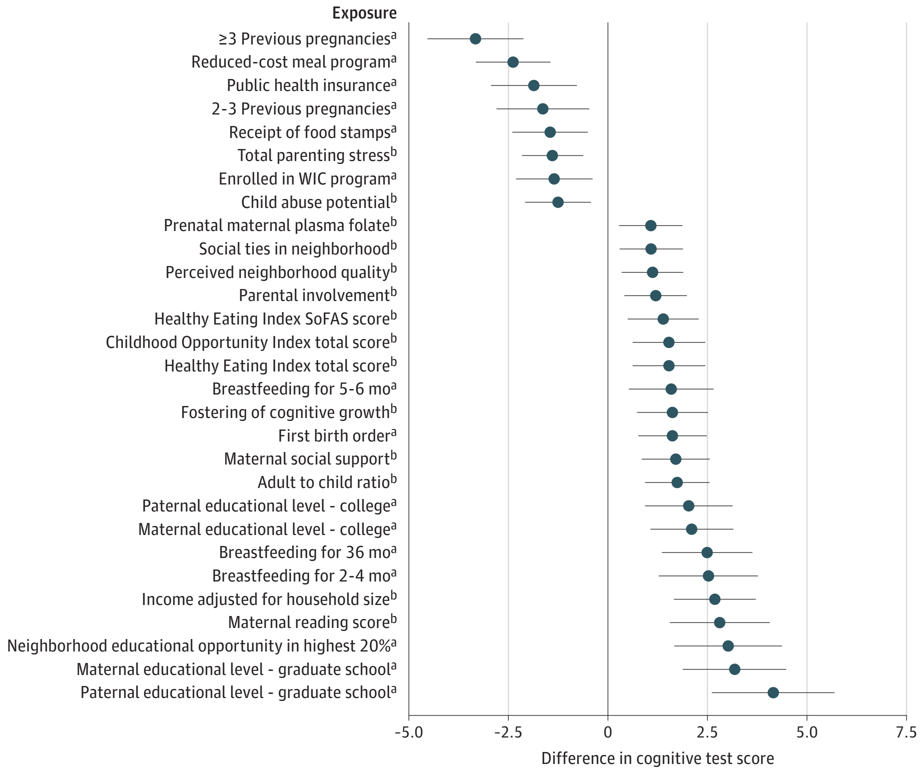
Characteristic	No. (%)	
	Included in analytic sample (n = 1055)	Excluded from analytic sample (n = 448)
Marital status		
Married	402 (38.1)	161 (35.9)
Widowed	1 (0.1)	0
Divorced	18 (1.7)	5 (1.1)
Separated	9 (0.9)	7 (1.6)
Never married	437 (41.4)	177 (39.5)
Living with partner	187 (17.7)	98 (21.9)
Missing	1 (0.1)	0

tial, maternal reading ability, and fostering of cognitive growth [assessed by trained behavioral coders who observed mothers and children completing interactive tasks]); and maternal nutrition during pregnancy and infant feeding (plasma folate in the second trimester, total score on the Healthy Eating Index [score range, 0-100, with higher scores indicating higher dietary quality], score on the solid fats and added sugars component of the Healthy Eating Index [score range, 0-20, with higher scores indicating lower consumption of solid fats and added sugars], and breastfeeding). Positive factors associated with cognitive performance at this stage included higher educational levels (ie, mother and father completed college or graduate school), high educational opportunity in the neighborhood, and high adjusted household income. Negative factors included 3 or more pregnancies, enrollment in a reduced-price meal program, and public health insurance, the latter 2 of which are also factors associated with low-income status.

A correlation matrix (eFigure in the Supplement) indicated associations between several of the 29 exposures; LASSO regression analysis excluded 5 exposures (public health insurance; receipt of food stamps; enrollment in the Women, Infants, and Children program; child abuse potential; and total score on the Child Opportunity Index). Adjusted associations for the remaining 24 exposures were assessed using 5 separate models. We examined exposures during childhood in a single model, which was adjusted for the a priori covariates included in stage 1 as well as prenatal nutrition exposures, breastfeeding, birth weight, and maternal race (model 1). Prenatal nutrition exposures were examined in separate models and included the a priori covariates as well as maternal and paternal educational levels, adjusted household income, neighborhood educational opportunity, and maternal race (models 2-4). Breastfeeding was adjusted for the a priori covariates as well as prenatal nutrition variables, maternal and paternal educational levels, adjusted household income, neighborhood educational opportunity, birth weight, and maternal race (model 5) (**Table 2**).

In the final models, 7 of the 24 exposures were associated with cognitive test scores and had 95% CIs that did not include the null. Cognitive test scores were positively associated with parental educational level. Compared with children of parents who had a high school education or less, children with mothers and fathers who completed graduate

Figure. Exposures Associated With Cognitive Test Scores



Difference in cognitive test scores and 95% CIs for the 29 exposures from the independent exposure-specific regression analyses that were adjusted for a priori covariates (ie, maternal cognitive test score, child's birth year, child's sex and age, and maternal and paternal ages at child's birth) and were retained after correction for false discovery rates. Black dots represent test scores, and black horizontal lines represent 95% CIs.

[a] Categorical exposure. For categorical variables, binary indicators for each category were created; the reference group included all other exposure categories. For example, for individuals with 3 or more previous pregnancies, the reference group included individuals with 0, 1, or 2 previous pregnancies. Because each indicator variable was evaluated in an independent multivariable regression analysis, all categories of a given variable (eg, maternal educational level) may not be represented in the figure if one of the categories did not meet the false discovery rate–corrected statistical threshold.

[b] Continuous exposure. All continuous variables were standardized using a mean of 0 and an SD of 1.0; thus, the reported difference in cognitive test scores corresponds with an increase of 1.0 SD in the continuous exposure. All exposures examined are described in eTable 1 in the Supplement. SoFAS indicates the solid fats and added sugars component of the Healthy Eating Index; WIC, Women, Infants, and Children program.

school had higher scores of 1.70 points (95% CI, 0.33-3.07 points) and 2.36 points (95% CI, 0.70-4.02 points), respectively. An increase of 1.0 SD in parenting stress was associated with a decrease of 1.04 points (95% CI, −1.86 to −0.21 points), while maternal reading ability and parenting behaviors that fostered cognitive growth were associated with increases of 1.42 points (95% CI, 0.16-2.68 points) and 1.12 points (95% CI, 0.24-2.00 points), respectively. Compared with the reference group (<2 months of breastfeeding), all categories of breastfeeding (2-4 months, 5-6 months, and ≥6 months) were associated with higher scores; 6 months or more of breastfeeding was associated with a higher score of 1.66 points (95% CI, 0.51-2.80 points). Using a heuristic approach to describe the potential impact of intervention for these exposures, we calculated the estimated marginal mean score for a child with reference values for these characteristics (ie, children with a score of 0 for continuous variables, children who were breastfed for <2 months, and children with parents who had a high school education or less) compared with a child who was breastfed for 6 or more months, had parents with college degrees, and had a mother whose reading level and observed fostering of cognitive growth scores were 1.0 SD higher than the mean and whose parenting stress level was 1.0 SD lower than the mean. Based on coefficients from the fully adjusted model (eTable 3 in the Supplement), a child with more beneficial exposures would have an estimated score of 116.2 points (95% CI, 111.2-121.2 points) compared with a reference child's score of 108.8 points (95% CI, 105.5-112.1 points), which represents a mean (SD) difference of 7.4 (0.5) points.

We observed no modification of associations by race or socioeconomic position, but greater statistical significance was found in the associations between cognitive test scores and paternal technical school education among girls (for girls, β = 3.13; 95% CI, 1.06-5.20; for boys, β = −0.92; 95% CI, −3.17 to 1.34; *P* = .03) and maternal graduate school education among boys (for boys, β = −3.09; 95% CI, −0.89 to 5.30; for girls, β = 0.60; 95% CI, −1.19 to 2.38; *P* = .05) (eTable 2 in the Supplement).

For all but 2 of the 24 exposures identified, Black children were less likely to be exposed to factors that are beneficial for cognitive performance, with notable differences in

Table 2. Fully Adjusted Models of Target Exposures Associated With Childhood Cognitive Test Scores at Age 4 to 6 Years

Exposure	Childhood cognitive test score, β (95% CI)	*P* value
Model 1: childhood characteristics[a]		
Family structure		
Previous pregnancies		
0 (First pregnancy)	1 [Reference]	NA
1	−0.48 (−1.86 to 0.91)	.50
2	−0.95 (−2.60 to 0.71)	.26
≥3	−1.64 (−3.46 to 0.17)	.08
Adult:child ratio[b]	0.44 (−0.58 to 1.45)	.40
First birth order compared with other birth order	−0.12 (−1.59 to 1.36)	.88
Mother's psychosocial factors		
Total parenting stress[b]	−1.04 (−1.86 to −0.21)	.01
Social support[b]	0.43 (−0.44 to 1.31)	.33
Perceived neighborhood quality[b]	0.36 (−0.43 to 1.14)	.37
Social ties in neighborhood[b]	0.43 (−0.37 to 1.24)	.30
Individual and neighborhood socioeconomic position		
Mother's educational level		
≤High school	1 [Reference]	NA
Technical school	1.08 (−0.11 to 2.27)	.07
College	1.36 (0.31 to 2.41)	.01
Graduate school	1.70 (0.33 to 3.07)	.02
Father's educational level		
≤High school	1 [Reference]	NA
Technical school	0.89 (−0.60 to 2.38)	.24
College	0.90 (−0.26 to 2.05)	.13
Graduate school	2.36 (0.70 to 4.02)	.005
Income adjusted for household size[b]	−0.26 (−1.47 to 0.96)	.68
Reduced cost meal program compared with no meal program	−0.43 (−1.55 to 0.69)	.46
Neighborhood educational opportunity quintile[c]		
1	1 [Reference]	NA
2	0.11 (−1.07 to 1.30)	.85
3	−0.35 (−1.50 to 0.81)	.56
4	−0.09 (−1.36 to 1.17)	.88
5	1.08 (−0.36 to 2.52)	.14
Parenting behaviors and cognitive enrichment		
Parental involvement (based on PRQ)[b]	0.50 (−0.31 to 1.31)	.23
Fostering of cognitive growth[b]	1.12 (0.24 to 2.00)	.01
Mother's reading ability[b]	1.42 (0.16 to 2.68)	.03
Models 2-4: prenatal nutrition[d]		
Prenatal nutrition		
Mother's plasma folate level (model 2)[b]	0.51 (−0.29 to 1.32)	.21
Heathy Eating Index score		
Total (model 3)[b]	0.82 (−0.11 to 1.74)	.08
SoFAS (model 4)[b]	0.78 (−0.11 to 1.68)	.09
Model 5: breastfeeding[e]		
<2 mo	1 [Reference]	NA
2-4 mo	2.30 (1.07 to 3.53)	<.001
5-6 mo	0.96 (−0.12 to 2.05)	.08
≥6 mo	1.66 (0.51 to 2.80)	.005

Abbreviations: NA, not applicable; PRQ, Parenting Relationship Questionnaire; SoFAS, solid fats and added sugars component of the Healthy Eating Index.

[a] Model 1 includes maternal cognitive test score, child sex, birth year, paternal age at child's birth, maternal age at child's birth, child age at assessment, maternal race, maternal plasma folate, Healthy Eating Index total score, Healthy Eating Index–SoFAS score, breastfeeding, and birth weight.

[b] Continuous variable. All continuous variables were standardized using a mean of 0 and an SD of 1.0. Coefficient estimates for continuous variables can be interpreted as the difference in cognitive test score points associated with an increase of 1.0 SD in exposure.

[c] Measured by the education domain of the Child Opportunity Index, with quintile 1 indicating 0% to 20% opportunity, quintile 2 indicating 21% to 40% opportunity, quintile 3 indicating 41% to 60% opportunity, quintile 4 indicating 61% to 80% opportunity, and quintile 5 indicating 81% to 100% opportunity.

[d] Models 2 to 4 include maternal cognitive test score, child sex, birth year, paternal age at child's birth, maternal age at child's birth, child age at assessment, maternal race, mother's education, father's education, adjusted household income, and neighborhood educational opportunity. Each prenatal exposure is modeled separately, as indicated.

[e] Model 5 includes maternal cognitive test score, child sex, birth year, paternal age at child's birth, maternal age at child's birth, child age at assessment, race, mother's education, father's education, adjusted household income, neighborhood educational opportunity, maternal plasma folate, Healthy Eating Index total score, Healthy Eating Index–SoFAS score, and birth weight.

prenatal nutrition, maternal reading ability, social support and social ties, neighborhood educational opportunity, breastfeeding, and multiple measures of SEP, including maternal educational attainment (**Table 3**). The unadjusted mean (SD) difference in test scores by race was 13.3 (11.6) points (mean [SD], 95.9 [14.1] points for Black participants and participants of other races vs 109.2 [12.3] points for White participants). In a mutually adjusted model that included all 24 exposures and covariates, we observed no difference in cognitive test scores by race (ie, the 95% CI for the race coefficient included the null) (eTable 3 in the Supplement).

Discussion

Our goal was to identify the most salient factors associated with childhood cognitive performance at age 4 to 6 years and the extent to which inequities in these exposures were associated with racial disparities. Of 155 prenatal and postnatal target exposures evaluated, 24 exposures were selected for inclusion in fully adjusted models; with the exception of birth order, all of these exposures could be considered modifiable. Exposures associated with cognitive performance included well-known factors, such as breastfeeding and parental educational levels, as well as factors that are understudied in epi-

Table 3. Distribution of Indicators of Cognitive Test Scores by Race in the Analytic Sample

Exposure	Race, No. (%) Black or other (n = 744)	Race, No. (%) White (n = 311)	*P* value
Family structure			
Number of previous pregnancies			
0 (first pregnancy)	202 (27.1)	110 (35.4)	<.001
1	191 (25.7)	95 (30.5)	
2	134 (18.0)	65 (20.9)	
≥3	217 (29.2)	41 (13.2)	
Adult:child ratio, mean (SD)	−0.06 (1.05)	0.16 (0.84)	<.001
First birth order	275 (37.0)	142 (45.7)	<.001
Mother’s psychosocial factors, mean (SD)			
Total parenting stress	−0.02 (1.05)	0.04 (0.88)	.45
Social support	−0.23 (0.89)	0.51 (0.97)	<.001
Perceived neighborhood quality	−0.10 (1.07)	0.24 (0.77)	<.001
Social ties in neighborhood	−0.23 (0.98)	0.56 (0.82)	<.001
Individual and neighborhood socioeconomic position			
Mother's educational level			
≤High school	362 (48.6)	64 (20.6)	<.001
Technical school	118 (15.9)	26 (8.4)	
College	178 (23.9)	117 (37.6)	
Graduate school	86 (11.6)	104 (33.4)	
Father's educational level			
≤High school	585 (78.6)	105 (33.8)	<.001
Technical school	46 (6.2)	29 (9.3)	
College	86 (11.6)	115 (37.0)	
Graduate school	27 (3.6)	62 (19.9)	
Income adjusted for household size, mean (SD)	−0.35 (0.76)	0.82 (1.02)	<.001
Reduced meal program	294 (39.5)	17 (5.5)	<.001
Neighborhood educational opportunity quintile[a]			
1	187 (25.1)	19 (6.1)	<.001
2	181 (24.3)	27 (8.7)	
3	213 (28.6)	24 (7.7)	
4	114 (15.3)	85 (27.3)	
5	49 (6.7)	156 (50.2)	
Parenting behaviors and cognitive enrichment, mean (SD)			
Parental involvement (based on PRQ)	0.03 (1.02)	−0.08 (0.91)	.12
Fostering of cognitive growth	−0.23 (0.92)	0.45 (0.83)	<.001
Mother’s reading ability	−0.46 (0.86)	0.63 (0.62)	<.001
Prenatal nutrition, mean (SD)			
Plasma folate	−0.17 (0.97)	0.41 (0.95)	<.001
Heathy Eating Index score			
Total	−0.29 (0.91)	0.49 (0.90)	<.001
SoFAS	−0.23 (0.89)	0.40 (0.98)	<.001
Breastfeeding			
<2 mo	359 (48.3)	43 (13.8)	<.001
2-4 mo	98 (13.2)	39 (12.5)	
5-6 mo	170 (22.8)	80 (25.7)	
≥6 mo	117 (15.7)	149 (48.0)	

Abbreviations: PRQ, Parenting Relationship Questionnaire; SoFAS, Solid Fats and Added Sugars.

[a] Measured by the education domain of the Child Opportunity Index, with quintile 1 indicating 0% to 20% opportunity, quintile 2 indicating 21% to 40% opportunity, quintile 3 indicating 41% to 60% opportunity, quintile 4 indicating 61% to 80% opportunity, and quintile 5 indicating 81% to 100% opportunity.

demiological cohorts, such as parenting stress, maternal reading ability, and a measure of observed maternal fostering of cognitive growth. When comparing estimated mean scores between a child with a moderate increase in these exposures and a child with reference values, we observed a mean difference of 0.5% of an SD. In a mutually adjusted model that included all target exposures and covariates, we observed no association between race and cognitive test scores.

Maternal reading ability was positively associated with childhood cognitive performance in a model adjusted for multiple confounders, such as maternal cognitive performance and educational level. Maternal reading ability is associated with the number of words spoken in the home and the literacy environment (eg, the number of books in the home)[37-39] and reflects the quality of the mother's early educational environment.[40] In the US, 14% of adults are illiterate, and 15% of adults graduate high school with only basic reading skills.[41] The quality of early educational environments varies substantially by socioeconomic position and race, which some have called the education debt to refer to the legacy of disparities in education access and quality[42] that is particularly prevalent in the southern US.[43] Addressing these disparities in educational quality is necessary to reduce the consequences of this legacy for the next generation of US children and to minimize inequitable downward trajectories in cognitive performance among children whose parents are in low-quality educational environments.

The fostering of cognitive growth, which was assessed by trained behavioral coders who observed mothers and children completing interactive tasks, was also positively associated with childhood cognitive performance. Psychological studies have reported similar associations between maternal behaviors that encourage cognitive growth and improved cognitive outcomes.[21,44] However, most parenting research using observed behavioral coding has relied on small samples of primarily White mother-child dyads without robust adjustment for potential confounders, such as socioeconomic position or breastfeeding.[45] We observed an association that was independent of family and neighborhood socioeconomic position, maternal cognitive performance and reading ability, birth weight, and breastfeeding. Notably, even in environments with high levels of adversity, parenting behaviors have been observed to change in response to intervention, with subsequent improvements in childhood cognitive development[46]; therefore, expanding accessibility to interventions aimed at improving parent-child interactions during cognitive tasks may help to improve childhood cognitive development.

Parenting stress was negatively associated with childhood cognitive test scores. Although raising a child with developmental delays is associated with increases in parenting stress,[47-49] longitudinal research describes these associations in children with typical development as bidirectional, such that parenting stress is associated with increased risk of worse outcomes for children.[50] Interventions to reduce parenting stress have been associated with improvements in the cognitive outcomes of children; although these interventions may have the most impact for parents of children with developmental delays, benefits have been observed for parents of all children.[51,52]

We also replicate previous studies that have reported positive associations between childhood cognitive performance and parental educational levels.[18,19] Although the coefficients for maternal educational level described in the present study are smaller than those of similar studies,[18,19] they are consistent with coefficients found in a study that accounted for shared genetic variance between siblings.[4] Our inclusion of multiple salient factors associated with childhood cognitive performance in the final models may produce more accurate coefficients within a cohort of unrelated children. While recent genome-wide association studies have developed polygenic risk scores to estimate educational attainment, the study with the most statistical power[53] explained only 11% to 13% of the variance. Among adopted children for whom the association between genetic factors and environmental conditions were addressed, the explained variance was further reduced.[54] In contrast, multiple overarching social factors associated with racial and socioeconomic disparities in educational attainment have been elucidated, including bans on affirmative action,[55,56] impoverished early-learning environments that inadequately prepare marginalized groups for higher education,[57,58] and attendance at undercapitalized universities in which dropout rates are higher.[59,60] In our sample, 71.1% of White mothers had a college education or more compared with 35.5% of Black mothers; our findings highlight the potential intergenerational impact of these socially driven patterns of educational attainment for childhood cognitive performance.

We adjusted for directly assessed maternal cognitive performance in all models; this adjustment is a strength of our study and provides evidence that the associations between exposures and childhood cognitive performance are not confounded by maternal cognitive ability. However, it is also important to note the likely inequities in the early learning environments of mothers in our study. Among adults from families with low socioeconomic positions, substantial variance in cognitive performance is associated with environmental factors.[8] Thus, our adjustment for maternal cognitive performance may yield conservative estimates of the associations between potentially modifiable socioeconomic factors and childhood cognitive performance given the intergenerational persistence of poverty in the US, which is more likely among minority groups.[61]

Although correlation coefficients in the present study are consistent with those of previous studies,[62,63] we did not observe a dose-response association between breastfeeding and cognitive test scores, which may be explained by our reliance on maternal retrospective reports. Children with mothers who had 3 or more previous pregnancies had lower cognitive test scores (although 95% CIs included the null), which is consistent with previous studies.[18,19] Despite the use of widely used, reliable survey instruments, maternal prenatal depression,[64] maternal experiences of interpersonal violence during pregnancy,[20] and birth weight and gestational age[18,19] did not meet the threshold for statistical significance in the independent models with minimal covariate adjustment (stage 1). We did not observe modification of associations by race or socioeconomic position.

Limitations

This study has several limitations. First, the estimated correlation coefficients from these models may be biased by unmeasured confounding. The intended use of our findings is to guide intervention studies and quasi-experimental research to further assess the associations between the identified factors and childhood cognitive performance. Second, important environmental exposures, such as lead, that are known to be associated with cognitive development and may be inequitably distributed by race were not measured in the CANDLE study.[65] Residual confounding from this type of exposure and measurement errors in the exposures that were included[57] may have produced an underestimation of the proportion of racial disparity in cognitive test scores associated with modifiable exposures. Third, differences in exposure assessment and measurement errors reduced our ability to directly compare exposure types. However, for most exposures, measurements were similar or had better reliability and validity compared with other longitudinal epidemiological cohorts. The CANDLE study excluded women with high-risk pregnancies at enrollment, and mothers had lower rates of preterm birth and low birth weight compared with the general population of Shelby County,[24] which may have limited our ability to detect associations for these exposures. Fourth, the results of the CANDLE study are largely representative of Shelby County, Tennessee, limiting their generalizability to the US population. However, our participants share characteristics with other primarily Black communities with high levels of socioeconomic disadvantage in urban areas of the southern US.

Conclusions

In an analysis that was well adjusted for potential confounding variables, we identified multiple modifiable factors associated with childhood cognitive performance that, if addressed, could help improve cognitive test scores. We conducted this study among a sample of children in the southern urban US, which comprises a population that is often underrepresented in large studies of childhood cognitive development.[18,19] In our study population, Black children experienced notably lower levels of most of the beneficial cognitive performance exposures, and inclusion of these exposures in a fully adjusted model accounted for the racial disparity in cognitive test scores. Our findings suggest that increasing equity in early social environments may help to reduce disparities in childhood cognitive performance.

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