Research on Child and Adolescent Psychopathology (2024) 52:521–533
https://doi.org/10.1007/s10802-023-01134-0

If Opportunity Knocks: Understanding Contextual Factors' Influence on Cognitive Systems

A. E. Gornik[1,2] · L. A. Jacobson[1,2] · L. G. Kalb[1,3,4] · A. E. Pritchard[1,2]

Accepted: 27 September 2023 / Published online: 16 October 2023

Abstract
Central to the Research Domain Criteria (RDoC) framework is the idea that RDoC constructs, which vary dimensionally by individual, are heavily influenced by contextual factors. Perhaps chief among these contextual factors is structural opportunity – the quality of resources available to a child as they grow. The aim of this study is to understand the impact of access to opportunity during childhood on three central RDoC cognitive systems constructs: language, visual perception, and attention. These constructs were measured using clinical data from psychological evaluations of youth ages 4–18 years (N = 16,523; M_{age} = 10.57, 62.3% male, 55.3% White). Structural opportunity was measured using the geocoded Child Opportunity Index 2.0 (COI), a composite score reflecting 29 weighted indicators of access to the types of neighborhood conditions that help children thrive. Findings indicate that, controlling for demographic and socioeconomic factors, greater access to opportunity is associated with significantly stronger cognitive skills across all three constructs. However, opportunity uniquely explains the largest proportion of the variance in language skills (8.4%), compared to 5.8% of the variance in visual processing skills and less than 2% of the variance in attention. Further, a moderating effect of age was found on the relation between COI and language skills, suggesting that the longer children remain exposed to lower levels of opportunity, the lower their language skills tend to be. Understanding how opportunity impacts cognitive development allows clinicians to offer better tailored recommendations to support children with cognitive systems deficits, and will support policy recommendations around access to opportunity.

Keywords RDoC · Language · Attention · Visual processing · Structural opportunity

Introduction

The Research Domain Criteria (RDoC) framework offers a dimensional conceptualization of fundamental psychological and biological systems that contribute to mental health and illness in the interest of understanding the full spectrum of these constructs (Insel et al., 2010). The framework consists of six major functional domains, each of which are represented by up to six constructs (Morris & Cuthbert, 2012). Critically, each of these constructs (and therefore domains) is fundamentally influenced by two universal factors: human development and the environment in which that development takes place (Morris & Cuthbert, 2012). Understanding the ways in which developmental and environmental factors shape a given domain is essential for improving outcomes, as these factors may be targeted for intervention.

The cognitive domain is, in the original RDoC framework, represented by six specific constructs: attention, perception (visual, auditory, and other sensory), language, declarative memory, cognitive control (goal selection, response selection, and performance monitoring), and working memory (Morris & Cuthbert, 2012). Cognition is an essential area for study, given its close association with important functional outcomes, including consistent links to a broad range of health, economic, well-being, and achievement-related outcomes (Der et al., 2009; Fergusson et al.,

✉ A. E. Pritchard
pritchard@kennedykrieger.org

1 Department of Neuropsychology, Kennedy Krieger Institute, Baltimore, MD, USA

2 Department of Psychiatry & Behavioral Sciences, Johns Hopkins University School of Medicine, Baltimore, MD, USA

3 Center for Autism & Related Disorders, Kennedy Krieger Institute, Baltimore, MD, USA

4 Johns Hopkins Bloomberg School of Public Health, Department of Mental Health, Baltimore, MD, USA

2005; Meisenberg, 2012; Sternberg et al., 2001). The aim of this study is to understand the association of environmental factors with three RDoC cognitive systems constructs: language, visual perception, and attention. These three particular constructs were chosen because they are central to functioning for children, are often assessed as part of routine care in clinical samples, and may be differentially related to environmental factors.

Relationship of Environmental Factors with Language, Visual Perception, and Attention

Since language is a primary marker of human development, a large body of literature has demonstrated the association between environmental factors and language skills. Numerous studies have consistently supported a link between language and socioeconomic status (SES)—a broad construct that is traditionally measured via household income, parental education or occupation, or, in some cases, a multidimensional index (e.g., the Barratt Simplified Measure of Social Status; Barratt, 2012)—with lower SES linked to poorer language skills as early as 18 months of age (Fernald et al., 2013). Growth in language skills tends to proceed more slowly during early childhood for children in lower SES families (Pungello et al., 2009), and language decrements tend to persist through adulthood and to be exacerbated over time (Hoff, 2006; Letourneau et al., 2013; Pakulak & Neville, 2010; Ramey & Ramey, 2004; Romeo et al., 2022). Similarly, higher levels of parental education have been linked to better language outcomes (De Marco & Vernon-Feagans, 2013). Neighborhood characteristics are also consistently found to be related to the development of language skills. Children who grow up in neighborhoods with higher income residents and lower family density, as well as those that are safer and have less disorder, tend to show better language skills (De Marco & Vernon-Feagans, 2013; Leventhal & Brooks-Gunn, 2003; Li et al., 2022; Vaden-Kiernan et al., 2010). Underlying mechanisms that have been proposed to explain some of these associations include characteristics of parent–child interactions (e.g., higher SES mothers' speech to their children is on average longer, more rich in vocabulary, and more complex; Hoff, 2003).

Visual perceptual development has received less attention than language. Like language, visual perception can be operationalized in multiple different ways, which may contribute to disparate findings. Also similar to language, lower SES has been consistently linked to poorer visual perceptual skills among children living in the United States (Carr et al., 2018; Casey et al., 2011; Jirout & Newcombe, 2015). The impact of SES on visual perceptual skills can be seen as early as the preschool years (Verdine et al., 2014, 2017) and tends to persist as children age (Jirout & Newcombe, 2015); however, these associations are often weaker than those of SES with language skills (Demir et al., 2015). The relationship between SES and visual perceptual skills has been hypothesized to be, at least in part, due to experience with spatial play (e.g., play with blocks and puzzles), given that spatial play is known to influence development of visual perceptual skills (Verdine et al., 2014); however, frequency of spatial play has not been found to vary with SES (Jirout & Newcombe, 2015). Mechanisms underlying the association between SES and visual perceptual skills remain unclear at this point.

Environmental factors relating to the development of attention have also been studied; however, the literature relating SES to attention is not entirely consistent. A recent meta-analysis of 33 studies indicated a significant positive association between SES and attention, with small to medium sized effects (Lawson et al., 2018). Level of parental education has also been found to be positively related to attention and cognitive control (Klenberg et al., 2001). In addition, neighborhood factors, such as poverty rates and quality of the physical environment (including amount of green space and air pollution), have been linked to cognitive and behavioral dysregulation and to rates of ADHD (Butler et al., 2012; Roy et al., 2014; Yuchi et al., 2022). While factors such as parenting, cognitive stimulation, and stress all vary with SES and may also contribute to attention, these remain only hypothetical underlying mechanisms (Lawson et al., 2018).

Clearly, many studies over the past few decades have examined specific environmental associations with the development of a particular cognitive skill. Taken together, this literature tends to support the idea that aspects of the environment in which children grow up are indeed related to cognitive skill development. Very few studies, however, have simultaneously examined specific environmental factors as they relate to multiple cognitive skills. Such studies are needed to understand the specificity of environmental exposure in relation to child cognition and to help reconcile discrepant findings from the few studies that have examined the association between SES and multiple cognitive outcomes. Noble and colleagues (2015) found a stronger association between household income and child language skills ($r = 0.206$) than between income and cognitive control ($r = 0.078$). Similarly, Taylor and colleagues (2020) found stronger relationships of household income and neighborhood poverty with language ability ($\beta = 0.28$ for household income and -0.18 for neighborhood poverty) than with cognitive control ($\beta = 0.13$ for household income and -0.12 for neighborhood poverty). In contrast, Romeo and colleagues (2022) found a slightly stronger relationship between SES and attention and cognitive control ($\beta = 0.10$) than between SES and language ($\beta = 0.08$).

Measurement of Environmental Factors

Environmental factors related to development have traditionally been measured individually, with variables such as family income, parental education, prenatal exposures, and neighborhood density evaluated separately from one another. None of these variables, alone, captures the whole of the environment in which a child is raised or the risk to which they are exposed. More recently, composite approaches to the measurement of environmental factors have been developed. While these composites also do not capture *all* of the variables that make up a child's environmental experience, they provide a more complete picture of the context in which a given child develops. Importantly, such measures are more replicable if they are publicly available, avoiding well-known measurement differences between studies. They also hold the capacity to be factor analyzed, allowing for reduction of measurement error.

The Child Opportunity Index (COI), initially developed in 2014 and revised in 2020, offers a sophisticated index of environmental factors that are uniquely relevant to youth (Noelke et al., 2020). The geocoded COI is designed to measure the quality of neighborhood resources available to a child as they grow, including affordable, high-quality early childhood education and schools, safe housing, healthy food, places to play outdoors, and clean air, in addition to measures of neighborhood economic prosperity. As such, the COI represents a particularly robust estimate of environmental variables – hereafter referred to as 'access to opportunity' to capture the breadth of environmental factors incorporated into the COI – that is well suited to extending the study of these factors in relation to cognitive constructs.

Significance of the Present Study

The present study offers several advantages over the existing literature. First, we simultaneously examined the relationship of development (i.e., age) as well as environmental factors with three critical cognitive systems in order to examine their relative association. Second, this study makes use of a sophisticated, composite index of environmental factors *that are uniquely relevant to youth* in order to optimize environmental measurement. Finally, this study takes advantage of a large clinical dataset that offers deep phenotyping of dimensional cognitive characteristics across developmental periods, from early childhood to young adulthood. This dataset captures youth growing up across the full range of environmental experiences, and as a clinical sample it includes youth at higher levels of risk than typical research samples, increasing variability in our cognitive and environmental constructs of interest.

Hypotheses

Based on the evidence from the existing literature on environmental factors related to cognition, we hypothesized that all 3 cognitive systems under investigation in the present study would be related to access to opportunity in childhood. No hypotheses were offered with regard to the relative associations of environmental access to opportunity with each construct, given the substantial inconsistency within the limited existing literature that addresses this issue. Instead, investigation into the relative associations with access to opportunity will be exploratory in nature. Finally, we hypothesized that age would moderate the relationship between access to opportunity and cognitive skills, such that this relationship would be stronger among older children who have had a longer exposure to contextual opportunities (or lack thereof).

Method

Participants

Data for this cross-sectional study were obtained from evaluations completed in a neuropsychology department in a large, urban academic medical center in the mid-Atlantic region of the United States. Data collected as part of routine clinical care since 2010 were used for this study. Youth referred for evaluation in the neuropsychology department represent a cohort of patients with neurodevelopmental and psychiatric concerns, with the five most common diagnoses in the subset of the sample for whom complete diagnostic information is available (n = 4421) were as follows: Attention-Deficit/Hyperactivity Disorder (ADHD; present in 64% of sample), anxiety (present in 40% of the sample), language disorders (present in 21% of the sample), learning disorder in reading (19% of the sample), and depression (17% of the sample). As part of standard workflow, families completed pre-visit intake forms and clinicians entered assessment data into the secure electronic medical record. From these records, a de-identified dataset was constructed following acknowledgement from the hospital's Institutional Review Board (IRB) that use of this deidentified dataset does not constitute human subjects research. Individuals were included if they were aged 4–18 at the time of their assessment, had an available Child Opportunity Index (COI) score, and had available data for at least one of the RDoC constructs of interest, described further below. For patients who had more than one assessment within the study timeframe, only data from the most recent assessment was included in order to ensure independence of observations. The COI score for a given participant estimates their access to opportunity, based on the address for them that was available in the medical record at the time of data retrieval for this study. In many cases, this address is the same as the participant's address at the time of their clinical evaluation, when the RDoC data were collected; however, in some cases the family may have moved in the interim, in which case their address would be different. In total, 16,523 unique patients, each with data from a single assessment, completed by a licensed clinical psychologist, were included. Descriptive statistics and sample sizes for the COI and each cognitive construct are detailed in Table 1.

The clinical sample was very heterogenous in terms of sociodemographic background. Individuals' age was on average 10.57 years (*SD* = 3.47). Child sex, race, and ethnicity, as reported by the caregiver, was extracted from the medical record. Patient race was available for 15,324 patients (92.7% of sample); of those with data provided, 55.3% were White, 30.9% were Black, 7.6% were multiracial, 1.1% were Asian/Pacific Islander, 0.2% were Native American/Alaskan Native, and 1.6% identified as "Other." "Hispanic, Latino/a, or Spanish" was also a response option for the race variable with 3.3% (n = 506) of patients identified as such. Some patients also provided data regarding ethnicity (n = 3,747, 22.7% of the sample), where an additional subset of caregivers endorsed a Hispanic, Latino/a, or Spanish ethnicity, for a total of n = 747 (4.9%) patients within the sample with a Hispanic, Latino/a, or Spanish background reported via race or ethnicity data. Approximately a third of children (37.7%) were female; due to medical record limitations, legal child sex was utilized in analyses rather than gender identity. The highest level of education obtained by the patient's primary caregiver was captured via pre-visit intake paperwork and available for 13,037 patients (78.9% of the sample), and utilized as a continuous variable in some analyses. Of those caregivers for whom education data were available, 17.5% (n = 2,277) completed some high school or obtained their high school diploma/GED; 28.2% (n = 3,673) obtained an associate's degree, tech/trade school, or completed some college; 25.9% (n = 3,382) obtained a 4-year degree; and 28.4% (n = 3,705) obtained an advanced degree.

Insurance type (i.e., commercial insurance vs. Medicaid/medical assistance insurance) was extracted from the medical record as an additional proxy for socioeconomic status in some analyses. Data on insurance type were available for 14,591 patients (88.3% of sample); of these, 71.7% of patients held commercial insurance (n = 10,458) and 28.3% held Medicaid/medical assistance insurance (n = 4,133).

Measures

Child Opportunity Index

The Child Opportunity Index 2.0 (Noelke et al., 2020) is a measure of structural opportunity for children. In this study, the COI scores were derived for each patient based on the census tract of their address. This reflects a much more proximal unit of measurement, compared to zip code. The COI is comprised of data from public and proprietary sources reflecting the year 2015. Within the measure, there are 29 indicators that are weighted by how strongly they predict economic and health outcomes. A total composite score as well as 3 subdomains are provided in the COI. Each score is then transformed to reflect a national ranking. The national COI scores, used in this study, range from 1–100, with a higher score indicating greater structural opportunity for the child.

The COI 2.0 includes three subdomain scores for neighborhood education, health/environment, and social/economic. The education domain score is derived from measures of early childhood education (e.g., enrollment in and availability of early childhood education centers within the

Table 1 Descriptive Statistics and Bivariate Correlations between COI and RDoC Constructs

	N	M (SD)	Range	1	2	3	4	5	6	7
1. Composite COI	16523	63.82 (29.67)	1–99	-						
2. Education COI	16523	62.45 (32.23)	1–99	0.903***	-					
3. Health/Environment COI	16523	64.75 (27.13)	1–99	0.830***	0.767***	-				
4. Social/Economic COI	16523	62.10 (28.88)	1–99	0.972***	0.790***	0.752***	-			
RDoC Constructs:										
5. Language (Standard Score)	7476	95.95 (17.28)	45–155	0.289***	0.271***	0.239***	0.276***	-		
6. Visual Processing (Standard Score)	6906	95.18 (17.33)	45–151	0.240***	0.240***	0.203***	0.220***	0.646***	-	
7. Performance-based Inattention (T Score)	2203	58.86 (13.26)	10–90	-0.138***	-0.136***	-0.129***	-0.129***	-0.153**	-0.176***	-
8. Parent-Reported Inattention	13261	15.84 (6.68)	0–27	-0.066***	-0.053***	-0.046***	-0.070***	0.007	-0.001	0.082**

A higher score on language and visual processing indicates a better performance, while a higher score on attentional measures indicates greater difficulty with inattention

COI Childhood Opportunity Index

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

census tract), elementary education (i.e., third grade reading and math proficiency on standardized tests), high school education (i.e., graduation rates, enrollment in Advanced Placement courses, and college enrollment in nearby institutions), and education-related resources (i.e., school poverty, teacher longevity, and adult educational attainment in the area). The health/environment domain score includes measures of healthy environments (i.e., access to healthy food and green space, walkability, and housing vacancy rates), toxic exposures (i.e., presence of hazardous waste dump sites, industrial pollutants and chemicals released by industrial facilities, airborne microparticles, ozone concentration, and extreme heat exposure), and health insurance coverage within the census tract. Finally, the social/economic domain is constructed of measures of economic opportunities (i.e., employment rate, commute duration) and resources (i.e., poverty rate, public assistance rate, home ownership rate, high-skill employment rate, median household income, and single-headed households). For in-depth details regarding measurement of the COI 2.0, see the Technical Documentation (Noelke et al., 2020).

Language

Language functioning was captured via the Verbal Comprehension Index (VCI) standard scores of the Wechsler tests (Wechsler, 1997, 2002, 2003, 2008, 2012, 2014), which are among the most frequently used and well-established assessments of cognitive functioning. Standard scores are norm-referenced such that the 50th percentile of performance for a given age falls at a standard score of 100, with a standard deviation of 15. VCI scores were derived from the Wechsler Preschool and Primary Scale of Intelligence, versions 3 and 4 (WPPSI-III, WPPSI-IV; n = 228 and n = 340, respectively), which spans age 2–7; the Wechsler Intelligence Scale for Children, versions 4 and 5 (WISC-IV, WISC-V; n = 2502 and n = 3729, respectively), which spans age 6–16; and the Wechsler Adult Intelligence Scale, versions 3 and 4 (WAIS-III, WAIS-IV; n = 17 and n = 660, respectively), which spans age 16 and up. While the subtests that comprise the VCI score change somewhat by the specific test, the composite score seeks to reflect constructs of expressive language, verbal reasoning, and verbal comprehension, with a higher score representing stronger language skills. Language data were available on 45.2% of the sample (n = 7476).

Visual Processing

Measures of visual processing were also assessed via composite index scores of Wechsler tests (i.e., the WPPSI-III, WPPSI-IV, WISC-IV, WISC-V, WAIS-III, and WAIS-IV; Wechsler, 1997, 2002, 2003, 2008, 2012, 2014). When a visual-spatial composite was available, this was used; otherwise, the overall perceptual/visual reasoning composite was used. Specifically, for the WPPSI-IV (n = 306) and WISC-V (n = 3193), the most recently updated Wechsler measures, the Visual Spatial Index (VSI) standard scores were utilized in order to better reflect visual processing as opposed to broader abstract reasoning skills. The VSI involves the organization of visual information, attending to visual detail, understanding whole-part relationships, and integrating visual and motor functions. For the remaining Wechsler tests, the composite reflecting visually-based processing/reasoning skills was utilized (i.e., the Performance Index of the WPPSI-III, n = 229; the Perceptual Reasoning Index of the WISC-IV, n = 2508; the Perceptual Organization Index of the WAIS-III, n = 16; and the Perceptual Reasoning Index of the WAIS-IV, n = 654). All visual processing scores are age-normed standard scores, with a mean of 100, a standard deviation of 15, and higher scores representing more well-developed skills. Visual processing data were available on 41.7% of the sample (n = 6906).

Attention

Attention was assessed via both a performance-based measure and a parent-reported attention rating.

Conners' Continuous Performance Test (CPT) Variability CPTs are widely utilized performance-based tasks that are administered via computer and assess specific cognitive components of attention, impulsivity, and executive control. For these tasks, a child is asked to press a given key whenever a target visual stimulus appears, and to inhibit a response when a non-target visual stimulus appears. Scores obtained from the Conners' CPT include measures of response times, within-person changes in reaction times and accuracy across the course of the task, and errors. The Conners' CPT can be administered to patients aged 8 and older, while the Kiddie Conners' CPT can be administered to patients aged 4 to 7. Administration of the Conners' CPT-2 (n = 950), CPT-3 (n = 1127), and K-CPT-2 (n = 126) were included (Conners, 2000, 2006, 2014). The CPT-2, CPT-3, and K-CPT-2 have acceptable internal consistency, with adequate test–retest reliability (Conners, 2000, 2006, 2014). Further evidence to support the validity of the Conners' CPT includes the finding that greater variability in response time is linked to more inattentive concerns as operationalized by a diagnosis of Attention-Deficit/Hyperactivity Disorder (ADHD; e.g., Kofler et al., 2013); thus, the Variability score on the Conners' CPT was utilized as the performance-based measure of attention for all analyses. Variability scores are normed by age and sex to T-score distributions (i.e., mean of 50 with a standard deviation of 10), with a higher T-score indicating greater challenges with attention. CPT data were available on 13.3% (n = 2203) of the sample.

Inattention Symptoms from the ADHD Rating Scales Caregiver/parent report on pre-visit intake rating scales assessing concerns for inattention in day-to-day life were obtained as part of routine clinical care using the inattention scale of the ADHD-RS measures. The ADHD-RS-5 reflects DSM-5 diagnostic criteria for ADHD, while the ADHD-RS-IV reflects DSM-IV diagnostic criteria (DuPaul et al., 1998, 2016). These measures have strong internal consistency, as well as adequate criterion-related, discriminant, and predictive validity (DuPaul et al., 1998, 2016). Both scales include 9 items assessing symptoms of inattention on a 4-point Likert scale ranging from 0–3 (never, sometimes, often, always). Total raw scores were obtained on each measure (i.e., range from 0 to 27, with a higher value indicating greater reports of inattention). ADHD-RS data were available on 80.2% (n = 13,261) of the sample.

Analytic Approach

The data analytic plan took a step-wise approach. First, bivariate Pearson's correlations were examined to determine the overall strength of the associations between each child's COI and their language skills, visual processing, and attention (i.e., the RDoC cognitive constructs of focus in the current study). Next, a series of linear regressions were conducted to determine the relationship between the COI and each cognitive outcome, above and beyond age and child sex, to compare the proportion of variance explained (i.e., R^2) in each cognitive construct by a child's access to structural opportunity. Linear regression analyses were then examined for interactions between age and COI (i.e., to determine if the cumulative number of years of exposure to a particular environment impacts the association to cognitive construct beyond age and COI alone), with conditional effects estimated via the PROCESS Macro Version 4.2 (Hayes, 2022). PROCESS is a widely used path analysis modeling tool that estimates direct and indirect effects in moderation and mediation analyses. Finally, while the focus of the current investigation was on COI as a robust metric of environmental context, which included surrounding educational attainment and economic advantage, we also examined whether neighborhood advantage continued to significantly explain a proportion of the cognitive constructs above and beyond traditional proximal measures of socioeconomic advantage; thus, regression analyses were run with age, child sex, insurance type, and parent education level. SPSS Version 28 was utilized for all analyses (IBM Corp, 2021).

Results

Use of Overall vs. Subdomain COI

Bivariate correlations between a child's COI, including COI subdomains, and each RDoC construct are provided in Table 1. Correlations ranged from r = 0.29 to r = -0.07, all of which were p < 0.001 due to the large sample sizes. Regression analyses are shown in Tables 2–4. As observed with the correlational analyses, the overall COI yielded the strongest associations to cognitive constructions, compared to the subdomains, in all cases but one (i.e., the Social/Economic domain of the COI indicated a greater R^2 value by 0.001 in parent-reported inattention). The difference in R^2 between the overall COI and subdomains in contributing to the outcome models was minimal (i.e., mean difference of 0.008). Therefore, the overall COI was exclusively used in analyses presented here, given the results of analytical exploration as well as the theoretical underpinning that the overall COI yields the most comprehensive and robust marker of a child's access to structural opportunity.

Language

Compared to visual processing and attention, language skills yielded the strongest bivariate correlation estimates with COI, $r = 0.29$, $p < 0.001$. Above and beyond age and child sex, a child's access to opportunity explained a notable proportion of the variance in language processing, R^2 change = 0.084, indicating that greater access to opportunity predicted better language skills; full model statistics can be found in Table 2. Importantly, there was a significant interaction between age and COI, which indicated that the effect of living longer in a particular area compounded the impact of the environment on language. Conditional effects of age on VCI were calculated at the 16^{th}, 50^{th}, and 84^{th} COI percentiles of the sample distribution to explore this interaction via PROCESS Macro Version 4.2 (Hayes, 2022). Results indicated that age was not significantly related to language for those at the 84^{th} percentile of COI within the sample, $t = -0.04$, $p = 0.97$. However, for children at the 16^{th} and 50^{th} percentiles, older age was significantly associated with poorer language skills, $t = -3.78$, $p < 0.001$ for 16^{th} percentile, $t = -2.08$, $p = 0.038$ for 50^{th} percentile. That is, regardless of age, children with highest levels of opportunity had the strongest language processing skills, and these stayed consistent across time; however, among children who have less access to opportunity, the *longer* they are exposed to these lower levels of opportunity, the worse their language skills fare. See Fig. 1. Children whose COI score fell at the 15th percentile, on average, had language skills that were 12.4 standard score points lower than children whose COI score fell at the 85th percentile. COI continued to predict a child's language skills above and beyond caregiver education and insurance type; see Table 3.

Table 2 Linear Regressions Predicting Language, Visual, and Attention Processing from Age, Child Sex, and COI

Outcome	Predictors	Model Effects	*F* Change	R^2 Change	*t*	B (*SE*)	β
Language	Overall Model	$F(4,7470) = 175.90^{***}$, $R^2 = 0.09$					
	Intercept				304.61***	94.92 (0.31)	
	Age		5.63	0.002	-2.95**	-0.56 (0.19)	-0.03
	Child Sex				2.16*	0.85 (0.39)	0.02
	COI		683.56	0.084	25.78***	5.20 (0.20)	0.29
	Age*COI		7.17	0.001	2.68**	0.53 (0.20)	0.03
Visual Processing	Overall Model	$F(3,6903) = 182.32^{***}$, $R^2 = 0.07$					
	Intercept				104.03***	88.38 (0.85)	
	Age		55.45	0.016	-7.88***	-0.45 (0.06)	-0.09
	Child Sex				6.98***	2.90 (0.42)	0.08
	COI		429.17	0.058	20.72***	0.15 (0.01)	0.24
Performance-Based Inattention	Overall Model	$F(3,2199) = 48.83^{***}$, $R^2 = 0.06$					
	Intercept				58.51***	73.15 (1.25)	
	Age		52.48	0.046	-10.09***	-0.84 (0.08)	-0.21
	Child Sex				-0.52	-0.29 (0.56)	-0.01
	COI		39.69	0.017	-6.30***	-0.06 (0.01)	-0.13
Parent-Reported Inattention	Overall Model	$F(3,13,253) = 35.35^{***}$, $R^2 = 0.01$					
	Intercept				68.74***	16.34 (0.24)	
	Age		25.11	0.004	-0.43	-0.01 (0.02)	-0.004
	Child Sex				6.83***	0.82 (0.12)	0.06
	COI		55.62	0.004	-7.46***	-0.02 (0.002)	-0.07

Language was entered as the outcome variable. *t* beta, and standard error values reflect statistics of the full model. Age and child sex were entered as one block, followed by COI as a separate block; for language, the interaction was also added as a separate block. Prior to creation of the interaction term for language, age and COI were standardized. The interaction between age and COI was not significant for visual processing or attention and thus is not reported here. Child sex: 0 = female, 1 = male. Higher values of language and visual processing indicate stronger performance, while higher values of inattention indicated *more concerns* for attention

COI Childhood Opportunity Index, *B* Unstandardized beta coefficient, *β* standardized beta coefficient

$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$

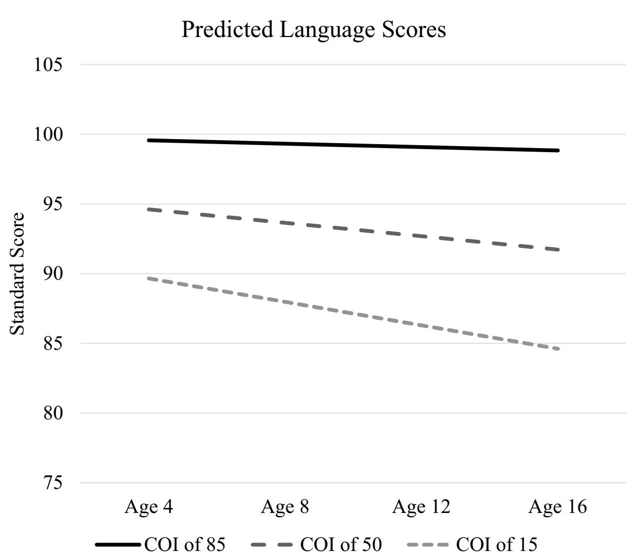

Fig. 1 Estimated Language Scores by Age and Childhood Opportunity Index. *Note*. Values reflect predicted language estimates at high, average, and low levels of the Childhood Opportunity Index (COI) at different ages. Higher language scores indicate stronger performance

Visual Processing

Associations between visual processing and COI were similar to, although slightly weaker than, the association found for language skills, $r = 0.24$, $p < 0.001$. COI predicted a significant proportion of the variance of visual processing above and beyond age and child sex, R^2 change = 0.058, such that youth living with greater opportunity had stronger visual processing skills; see Table 3. Children whose COI score fell at the 15th percentile, on average, had visual processing skills that were 10.3 standard score points lower than children whose COI score fell at the 85th percentile. The interaction between age and COI on visual reasoning was not significant, indicating that the association of neighborhood opportunity on visual processing skills was similar across child age. It was, therefore, excluded from the model by the PROCESS Macro. Similarly to language skills, the association between COI and visual processing was significant above and beyond caregiver education and insurance type; see Table 3.

Table 3 Stepwise Linear Regressions Predicting Language and Visual Processing by Sociodemographic Patient Characteristics and COI

	Outcomes:					
	Language			Visual Processing		
Predictors:	*t*	B (*SE*)	β	*t*	B (*SE*)	β
Model 1	$F(2,7472) = 5.63^{**}$, $R^2 = 0.001$			$F(2,6902) = 55.45^{***}$, $R^2 = 0.02$		
Age	-2.29*	-0.13 (0.06)	-0.03	-7.50***	-0.44 (0.06)	-0.09
Child Sex	2.33*	0.96 (0.41)	0.03	6.98***	2.98 (0.43)	0.08
Model 2[a]	$F(4,4725) = 107.03^{***}$, $R^2 = 0.08$			$F(4,4262) = 94.21^{***}$, $R^2 = 0.08$		
Age	-1.57	-0.11 (0.07)	-0.02	-6.34***	-0.45 (0.07)	-0.09
Child Sex	1.08	0.53 (0.49)	0.02	4.98***	2.57 (0.52)	0.07
Insurance	11.70***	7.87 (0.67)	0.18	11.50***	8.18 (0.71)	0.18
Parent Ed	11.44***	2.81 (0.25)	0.17	8.08***	2.09 (0.26)	0.13
Model 3[a]	$F(3,4727) = 186.34^{***}$, $R^2 = 0.11$			$F(5,4261) = 89.41^{***}$, $R^2 = 0.10$		
Age	-	-	-	-6.49***	-0.46 (0.07)	-0.10
Child Sex	-	-	-	4.85***	2.49 (0.51)	0.07
Insurance	8.14***	5.65 (0.69)	0.13	8.81***	6.49 (0.74)	0.14
Parent Ed	9.18***	2.26 (0.25)	0.14	6.43***	1.68 (0.26)	0.10
COI	11.13***	0.11 (0.01)	0.17	8.04***	0.08 (0.01)	0.13

Higher values on language and visual processing measures indicated stronger performance. Child sex: 0 = female, 1 = male; insurance type: 0 = Medicaid, 1 = commercial

COI Childhood Opportunity Index, *B* unstandardized beta coefficient, *β* standardized beta coefficient

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

[a]Only predictors that were significant in prior models were entered into subsequent models

Attention

Measures of attention were the least associated with COI. While parent-reported inattention utilizes a different assessment method than a performance-based measure (i.e., as were used with language and visual processing) and thus may be anticipated to yield different association patterns due to method variance, our performance-based measure of inattention also had a weaker association with COI than was observed for language or visual processing (i.e., $r = -0.14$, $p < 0.001$, for performance-based inattention; $r = -0.07$, $p < 0.001$, for parent-reported inattention). Despite the relatively weak associations, COI was still a significant correlate of both parent-reported and performance-based inattention, with more opportunity linked to greater attentional skills; see Table 4. Children whose COI score fell at the 15th percentile, on average, had performance-based attention skills that were 4.1 T-score points higher (i.e., worse performance), and parent-reported attention that was 1 raw score point lower, than children whose COI score fell at the 85th percentile. There was no significant interaction between COI and age, indicating that opportunity was similarly associated with attention across ages. For both measure of attention, COI remained significant above and beyond proximal family measures of socioeconomic status; see Table 4.

Discussion

The goal of our investigation was to compare how several constructs within the cognitive RDoC domain – language, visual processing, and attention – cross-sectionally assessed over the course of child development were associated with environmental factors that are especially impactful to youth. Results indicated that a robust, composite estimate of structural opportunity that combined three aspects of the child's environment (social/economic setting, health/environment, and educational surroundings) was more strongly related to cognitive functioning than any single aspect of the environment alone. This suggests that each aspect of the environment is critical to understanding children's structural opportunity and its associations with language, visual processing, and attention.

Our study yielded three important findings. First, while structural opportunity accounted for a proportion of the variance in all three constructs, it uniquely explained the largest proportion of the variance in language skills (i.e., approximately 8.4%, compared to 5.8% of visual processing skills and less than 2% of attention). On performance-based measures of language, visual processing, and attention, the predicted difference between children at the 15th and the 85th percentile of structural opportunity was clinically

Table 4 Linear Regressions Predicting Attention Processing by Sociodemographic Patient Characteristics and COI

	Outcomes:					
	Performance-Based Attention			Parent-Reported Attention		
Predictors:	*t*	B (*SE*)	β	*t*	B (*SE*)	β
Model 1	$F(2,2200) = 52.48$***, $R^2 = 0.05$			$F(2,13,254) = 25.11$***, $R^2 = 0.004$		
Age	-10.24***	-0.86 (0.08)	-0.21	-0.78	-0.01 (0.02)	-0.01
Child Sex	-0.60	-0.33 (0.56)	-0.01	6.98***	0.84 (0.12)	0.06
Model 2[a]	$F(4,1404) = 37.53$***, $R^2 = 0.07$			$F(3,11,081) = 60.67$***, $R^2 = 0.02$		
Age	-8.89***	-0.94 (0.11)	-0.23	-	-	-
Child Sex	-	-	-	6.41***	0.84 (0.13)	0.06
Insurance	-4.63**	-4.20 (0.91)	-0.13	-8.17***	-1.26 (0.15)	-0.08
Parent Ed	-1.26	-0.46 (0.36)	-0.03	-4.33***	-0.28 (0.07)	-0.05
Model 3[a]	$F(4,2012) = 57.45$***, $R^2 = 0.08$			$F(4,11,080) = 47.08$, $R^2 = 0.02$		
Age	-10.20***	-0.89 (0.09)	-0.22	-	-	-
Child Sex	-	-	-	6.37***	0.83 (0.13)	0.06
Insurance	-5.56***	-4.05 (0.73)	-0.13	-6.92***	-1.13 (0.16)	-0.08
Parent Ed	-	-	-	-3.79***	-0.25 (0.07)	-0.04
COI	-3.10**	-0.03 (0.01)	-0.07	-2.49**	-0.01 (0.003)	-0.03

A higher value on attention processing measures indicated *more difficulties* with attention. Child sex: 0 = female, 1 = male; insurance type: 0 = Medicaid, 1 = commercial

COI Childhood Opportunity Index, *B* unstandardized beta coefficient, *β* standardized beta coefficient

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

[a]Only predictors that were significant in prior models were entered into subsequent models

meaningful. Children whose COI score fell at the 15th percentile, on average, had language skills that were 12.4 standard score points lower, visual processing skills that were 10.3 standard score points lower, and attention skills that were 4.1 T-score points (equivalent to approximately 6 standard score points) lower than children whose COI score fell at the 85th percentile. This represents nearly a standard deviation difference in language skills (e.g., the difference between an average and a below average score), two-thirds of a standard deviation difference in visual-spatial skills, and almost half a standard deviation difference in attention. Second, although our data are cross-sectional, our age-related findings suggest that the longer a child has lived in a given environment and been exposed to a particular level of opportunity, the stronger the relationship between structural opportunity and language skills. This was not true, however, for visual processing or attention – length of exposure to structural opportunity did not affect the strength of the relationship between opportunity and these cognitive constructs.

These findings, along with our finding that language was the construct most strongly related overall to environment, suggest that language may be a cognitive domain that is particularly sensitive to environmental influences in a way that accumulates over time. In this study, environment was less strongly related to visual processing and attention and did not appear to have a cumulative impact on these constructs. In addition to the explanation that language may be cumulatively impacted over time, it is also possible that as children age, the environment that they are in becomes more strongly related to their language functioning; alternatively, perhaps early exposure to lower levels of opportunity set the child on a developmental pathway that creates increasing language gaps as they age, regardless of later environmental opportunities. At this time, it is unclear why the language system is particularly related to access to opportunity, and future research investigating underlying mechanisms, such as parenting characteristics or exposure to enrichment experiences, may be valuable.

Our results are consistent with and extend prior work identifying the strong connection between language development and environmental factors (e.g., De Marco & Vernon-Feagans, 2013; Fernald et al., 2013; Hoff, 2006; Letourneau et al., 2013; Leventhal & Brooks-Gunn, 2003; Li et al., 2022; Pakulak & Neville, 2010; Pungello et al., 2009; Ramey & Ramey, 2004; Romeo et al., 2022; Vaden-Kiernan et al., 2010). Few studies have directly simultaneously compared environmental associations with multiple cognitive domains, including language skills. Those that have find somewhat less variability in the strength of the environment-cognitive construct relationship across constructs (i.e., bivariate correlations in the current study ranged from -0.07 for inattention and COI to 0.29 for language and COI, as compared to correlations ranging from 0.08 to 0.21 in Romeo et al., 2022 and Noble et al., 2015's work). This may be due to our comprehensive, composite measure of structural opportunity as well as our use of well-validated cognitive assessment measures within a diverse clinical population. Our work also helps to clarify the mixed prior evidence for the relationship between environment and visual-spatial skills and attention (e.g., Castagna et al., 2022; Lawson et al., 2018; Jirout & Newcombe, 2015; Verdine et al., 2014, 2017), and is in line with the work of Noble et al. (2015) that language is more strongly related to the environment than attention. Similarly, one community/population-based study that utilized the National Institutes of Health Toolbox Cognitive Battery with measures of verbal ability, attention and executive functioning, working memory, processing speed, episodic memory, and reading ability found that while children's performance on all measures were related to neighborhood advantage, children's verbal ability was most strongly related (Taylor et al., 2020).

Of note, within two studies that examined multiple cognitive domains, Romeo and colleagues (2022) suggested that differences in executive function skills may be partially explained by differences in language skills, and Demir et al. (2015) similarly suggested that differences in use of verbal and visuo-spatial neural regions of interest in solving arithmetic problems appear based in SES-related language skill differences. Thus, it is possible that structural opportunity is most strongly linked to language skills, which potentially partially mediates the relationship between structural opportunity and visual-spatial skills as well as attention. Future studies may be helpful in further exploring this mediation.

Before discussing the clinical implications of these findings, it is important to explicitly address the issue of causal inference as it relates to this study. The cross-sectional design of the present study does not support causal inference, and, as noted in the introduction, the mechanisms underlying the associations reported here and in previous studies remain poorly understood; although, it is well established that there is an interplay between environment and genetic predisposition in many aspects of a child's functioning. This necessarily complicates discussion of clinical implications, which tend to presume a causal relationship. It is therefore important to note, in the upcoming discussion of implications of the findings of this study, that these implications must be viewed as tentative, at this point, until future research demonstrates the causal direction and underlying mechanisms of the associations identified here.

Several possible clinical and policy implications may stem from these findings. Language skills, which were the area most strongly related to structural opportunity, have an extensive literature base demonstrating responsivity to intervention, often through speech-language therapy (e.g., as reviewed in Boyle et al., 2010; Law et al., 1996; Roberts & Kaiser, 2011) or parent training on early literacy. Results of this study suggest that children who reside in places with minimal access to structural opportunity may benefit from intervention to help develop language skills, potentially in part through work with caregivers. This may be especially important in the absence of a diagnosable language disorder or delay, as children with delays should be identified and receive intervention in the United States via the Child Find mandate under the Individuals with Disabilities Education Act. Pediatricians, who are often in the position of providing and facilitating early referrals to families, including Child Find referrals, may be able to take a child's structural opportunity into account and provide targeted referrals for evaluation. Furthermore, clinicians assessing children need to be aware of the opportunities available to them within their communities, in order to tailor recommendations to be accessible to the child and family (e.g., knowledge of summer literacy and language programs provided within communities, such as at local libraries or sliding-scale programming). They should also consider, in interpreting assessment results, how a child's environmental context may be related to their skill development, rather than thinking of a child's skills in a given domain as a static reflection of their innate capacity.

From a broader perspective, these results support policy that seeks to promote equity and access to opportunity, as structural opportunity clearly is significantly associated with children's cognitive development. Relevant policy initiatives, based on this study, are diverse and should target areas of structural opportunity captured by the COI. Policy initiatives such as those designed to increase health insurance coverage, access to healthy food, employment rates, and educational quality, might be expected to positively impact children's cognitive development. Additionally, given the positive impacts observed in the Moving to Opportunity (MTO) studies (e.g., Chetty et al., 2016; Leventhal & Brooks-Gunn, 2003), providing financial support and offering families with children the chance to relocate to areas rich in structural opportunity may also be a viable option. Compared to controls, moving to a low-poverty neighborhood increased college attendance, increased wages, promoted better mental health, and reduced rates of risky behaviors and single parenthood.

There are many unique advantages to the current study, including the simultaneous examination of multiple cognitive constructs, the strong composite index of environmental influences developed to be specifically relevant to youth, inclusion of both performance-based and parent-reported measures of attention, and our large and diverse clinical sample that captures youth at higher levels of risk with greater variability in performance than are typically captured in research samples. However, there are several limitations to the current study to acknowledge. While use of a clinical sample is a strength overall, this population is not representative of the wide range of typical functioning in youth, as youth are typically referred for psychological and neuropsychological evaluations related to some form of neurodevelopmental, psychiatric, or medical complexity. Thus, it is possible that structural opportunities across childhood may have stronger or weaker associations with these cognitive constructs in a more typically-developing sample. Of note, however, the magnitude of the associations between language and environment and between attention and environment found in the present study is quite similar to the magnitude of these associations found in a large population-based study of youth (Taylor et al., 2020), despite this study using different measures of both cognitive constructs and disadvantage. As such, concerns related to generalizability of the present study's findings may be somewhat ameliorated. In calculating the Childhood Opportunity Index from our medical records, the most current address on file was used, and this may obscure the impact of potential change in structural opportunity over time as families move. However, while household moves are not uncommon, the vast majority of families tend to remain in lower-poverty or higher-poverty census tracts (e.g., Leibbrand & Crowder, 2018; South et al., 2005). Additionally, operationalizations of visual perceptual skill vary considerably within the literature, which may explain the somewhat mixed findings in this domain. While our operationalization of visual perception differs from some of the existing literature in this area, it is based on a well standardized, widely used measure that may allow for easy testing of replicability and generalizability. Of note, while the excellent reliability of the Wechsler measures utilized for visual perceptual skills and language is well-replicated, there has been limited replication assessing the reliability of our performance-based measure of attention (i.e., Conners CPT Variability) outside of the Conners manuals (e.g., Conners, 2014); thus, it is possible that the weaker relationship between COI and our performance-based measure of attention may be in part due to attenuation from unreliability. Finally, our data were cross-sectional and there was substantial missingness due to personalized selection of cognitive measures by clinicians, both of which limit causal inference, as discussed earlier.

Taken together, results of this study indicate a significant association between developmental and environmental factors and several constructs within the RDoC cognitive domain (Morris & Cuthbert, 2012). In particular, language skills are especially closely tied to structural opportunity. Consideration of direct intervention efforts to target language development as well as indirect intervention efforts through policy change and legislative advocacy to promote equity is warranted.

Funding This work was supported by the Intellectual and Developmental Disabilities Research Center at Kennedy Krieger Institute, NIH funded by Eunice Kennedy Shriver National Institutes of Child Health and Human Development (NICHD) award number P50 HD103538.

Data Availability The data that support the findings of this study represent pediatric clinical data from a medical records system, studied under a waiver of consent and, as such, are not eligible to be shared due to their sensitive nature.

Compliance with Ethical Standards

Ethical Approval Ethical approval for the conduct of this research was provided from the Johns Hopkins University School of Medicine's Institutional Review Board.

Informed Consent This research was conducted retrospectively using clinical data under a waiver of informed consent (HIPAA Form 4).

Conflict of Interest The authors have no relevant financial or non-financial interests to disclose.

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