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Building foundations: How neighborhood social and built environment factors impact children's learning

Edited by
Parisa Parsafar and Brett Miller

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Building foundations: How neighborhood social and built environment factors impact children's learning

Topic editors
Parisa Parsafar — Eunice Kennedy Shriver National Institute of Child Health and Human Development (NIH), United States
Brett Miller — National Institutes of Health (NIH), United States

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EDITED BY
Brett Miller,
National Institutes of Health (NIH),
United States

REVIEWED BY
Maya L. Rosen,
University of Washington, United States
Derek John Clements-Croome,
University of Reading, United Kingdom

*CORRESPONDENCE
Caitlin F. Canfield
caitlin.canfield@nyulangone.org

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Not built for families: Associations between neighborhood disinvestment and reduced parental cognitive stimulation

Caitlin F. Canfield[1]*, Lauren O'Connell[2], Richard C. Sadler[2], Juliana Gutierrez[1], Shanna Williams[3] and Alan L. Mendelsohn[1]

[1]Division of Developmental-Behavioral Pediatrics, Department of Pediatrics, NYU Grossman School of Medicine, New York, NY, United States, [2]Division of Public Health, Michigan State University College of Human Medicine, Flint, MI, United States, [3]Michigan State University College of Human Medicine, Michigan State University-Hurley Children's Hospital Pediatric Public Health Initiative, Flint, MI, United States

Infants learn and develop within an ecological context that includes family, peers, and broader built and social environments. This development relies on proximal processes—reciprocal interactions between infants and the people and environments around them that help them understand their world. Most research examining predictors of proximal processes like parent-child interaction and parenting has focused on elements within the home and family. However, factors like the neighborhood built environment may also exhibit an influence, and may be particularly critical in infancy, as socioeconomic disparities in cognition and language emerge early in life. Moreover, influence from the built environment could independently exacerbate these disparities, as research indicates that neighborhood impacts may be especially relevant for families living in neighborhoods that have experienced disinvestment and therefore have been under-resourced. The current study examines these questions by determining the association of neighborhood vacancy rate and observed physical disorder—indicators of poverty, residential stability, and long-term structural discrimination—with parental cognitive stimulation among predominantly Black/African-American families in Flint, Michigan. Flint is particularly salient for this study because vacancy rates and disinvestment vary widely across the city, driven by its long-time status as a city struggling economically. Regression analyses controlling for caregiver education, mental health, and social support indicated that vacancy rate and physical disorder negatively predicted parental cognitive stimulation. Moreover, there were significant interactions between the built environment and social support, indicating that, particularly for parent-child shared reading, vacancy rate and physical disorder predicted reduced shared reading only when parents had limited social support. These results have important implications for public policy around vacant property demolition and neighborhood reinvestment programs, as they indicate that the neighborhood built environment is associated with parenting behaviors that have important impacts on infants' learning and development.

KEYWORDS

neighborhood, parenting, built environment, infancy, disinvestment

Introduction

Early environments are critical for children's development (Bradley et al., 1989; Dieterich et al., 2006; Rowe, 2012; Cabrera et al., 2017). Impacts of family, neighborhood, and structural/institutional factors are evident even in early infancy (Burchinal et al., 2008), and have lasting impacts on learning, academic achievement, economic attainment, and mental and physical health (Duncan et al., 2010). Further, the impacts of the environment may be greater for children living in poverty or who otherwise face increased risk (McCartney and Berry, 2009; Ungar and Hadfield, 2019). However, while several studies have shown that neighborhood poverty levels and social factors impact parenting and child outcomes (Klebanov et al., 1994; Olofson, 2017; Li et al., 2022), few have examined the impacts of the neighborhood built environment on families with infants and young children, and even fewer examine them using precise (i.e., individual level data rather than data aggregated by zip code or census tract) and novel measures of the built environment. This study sought to fill this gap by examining the impact of built environment disinvestment at the neighborhood level on proximal processes of infant learning—namely, parenting behaviors—in Flint, Michigan, integrating tenets from Bronfenbrenner's bioecological model, differential impact theory (DIT), and the weathering hypothesis.

How neighborhoods impact development: Theoretical frameworks

The bioecological model (Bronfenbrenner and Morris, 2007) posits that human development takes place through reciprocal interactions between that person and the people, objects, and environments around them. These proximal processes must occur regularly or over an extended period of time and enable young children to make sense of their world. Moreover, proximal processes vary across people and environments, and their content and significance changes according to the developmental outcome under study and the time at which they take place, both in terms of the life course and the historical period. In this process-person-context-time (PPCT) framework (Tudge et al., 2009), proximal processes, such as parenting behaviors, are critical for infant learning and influence infant development in different ways depending on both characteristics of the infant and their environment.

Environmental and contextual factors may further differentially impact infants and their parents. Differential impact theory (Ungar, 2017) focuses on how these factors affect epigenetic, neurological, cognitive, and socioemotional development. DIT includes three principles: that the environment can affect and change people at multiple levels (e.g., biological, psychological, social); that an individual's outcome is dependent on their level of risk exposure; and that an understanding of the multisystemic nature of individual outcomes is necessary in order to determine how to improve wellbeing. And yet, measurement of the built environment is often limited by poorly geocoded individual data or aggregated environmental data (for example, data compiled at a ZIP code or county level rather than at an address level).

Finally, the weathering hypothesis (Forde et al., 2019) suggests that chronic exposure to social and economic disadvantage leads to suboptimal health outcomes, including earlier onset of physical health conditions. In the U.S., this weathering accounts at least in part for health disparities for Black/African-American citizens who are more likely, because of systemic racism, to have lower education and income, and to live in disadvantaged neighborhoods. However, conceptualizations of weathering are often limited to contemporary measures of socioeconomic status, rather than longer time-horizon considerations of historical structural racism in the built and social environment. Further, while this has primarily been applied to physical health outcomes, there is evidence that such chronic exposure impacts proximal processes for infant cognitive development (Luke et al., 2009), as the disadvantage experienced by Black/African-American and other marginalized parents makes it more difficult for them to engage in responsive parenting behaviors like shared reading and teaching.

Taken together, these theories indicate that the community context plays a critical role in human development, both through exposure to risk and disadvantage, and through impacts on proximal processes that underlie physical, cognitive, and socioemotional growth. When considering infant learning, therefore, we would expect neighborhoods and

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other environments to have both direct impacts on infants' development, and indirect effects through impacts on parenting behaviors, such as play and shared reading, that promote cognitive development. Novel methodological advances in the measurement of the neighborhood environment will allow for a more nuanced understanding of this association.

Neighborhoods and development in infancy and early childhood

Research examining the impacts of neighborhoods on children and families has primarily focused on broad measures of neighborhood advantage or disadvantage. These studies provide preliminary support for the theoretical framework above. For instance, early research on the effects of neighborhood poverty on maternal characteristics and behaviors indicated that the proportion of neighborhood residents with low incomes was significantly associated with the physical environment within the home and warmth between the mother and child (Klebanov et al., 1994). Similarly, effects of poverty at the neighborhood level, including increased social disorder and lower levels of social cohesion, have been associated with increased parenting stress (Franco et al., 2010). On the other hand, neighborhood affluence is associated with more positive parenting practices (e.g., reduced physical discipline) through effects of increased neighborhood resources and services (Shuey and Leventhal, 2017).

Neighborhood disadvantage also has impacts on learning and development in young children. For instance, neighborhood disorder is associated with disrupted sleep at age one and through that association with decreased language development at age five (Li et al., 2022). Further, research has found specific impacts of the neighborhood environment on brain development. For instance, Hyde et al. (2020) found that although family income, maternal education, and neighborhood poverty were all related to performance on a go/no-go inhibitory control task, only neighborhood poverty was related to neural activity during the task. They further found that the proportion of families living below poverty and the median family income of a neighborhood uniquely predicted amygdala reactivity to ambiguity. Children living in neighborhoods marked by these indicators of poverty showed a heightened amygdala response to neutral faces, indicating increased emotional reactivity. Finally, infants born prematurely and living in high-risk neighborhoods were more likely than their peers in low-risk neighborhoods to have neurodevelopmental impairment, or a cognitive or language delay at age two, even after adjusting for maternal education, non-English-speaking parent, gestational age, presence of medical complications associated with prematurity, and breastfeeding (Nwanne et al., 2022).

The specific impacts of the built environment

Much of the prior research in this field has looked broadly at poverty or at social risks within neighborhoods. However, other neighborhood attributes, such as institutional resources (e.g., libraries, child care facilities and schools, healthcare facilities, services and retailers), have important impacts on families and children's development (Wei et al., 2021). The neighborhood built environment may be an additional factor that influences learning and development. Several studies have examined the impact of the built environment on children's physical health. These have indicated that more walkable neighborhoods, including those with safe sidewalks, crossings, and destinations that are reachable by foot, bicycle, or public transportation, are associated with increased physical activity (Villanueva et al., 2016), and that air pollution and other environmental exposures closely related to the built environment are associated with health outcomes, including fetal growth and child respiratory health (Gascon et al., 2016).

There is reason to believe that influences of the built environment go beyond physical health alone, and may disrupt the proximal processes critical to early development in the same way that broader neighborhood indicators do. For instance, living in areas with fewer main, high-speed roads has been associated with a decreased risk for developmental vulnerability (Christian et al., 2017), and increased access to nature and green spaces has been linked to improved child mental health (Alderton et al., 2019). Further, the increased physical activity associated with walkable neighborhoods may also benefit young children's cognitive development, and such neighborhoods support social resources, such as social networks and collective efficacy, which promote responsive parenting and children's socioemotional wellbeing (Villanueva et al., 2016). On the other hand, neighborhoods that have experienced disinvestment and economic decline often lack the community resources, such as green space, clean air, safe streets, and even grocery stores, that have previously been shown to have positive impacts on children's development (Walker, 2021). These same places are associated with lower rates of collective efficacy, social capital, psychological wellbeing, stability, and other elements important to the healthy development of families (Walker, 2021; Berg et al., 2022). This lack of physical and social infrastructure translates to higher rates of neighborhood stressors, and increased exposure to psychosocial risks, which, in turn leads to increased parent stress and mental health symptoms, reduced parental capacity to provide cognitively stimulating experiences (Cuellar et al., 2015), and more negative interactions with their children (Morrison Gutman et al., 2005). Parenting is thus more challenging in such places, particularly when viewed through the historical lens of practices like redlining that marginalized such communities even before physical and social disorder set in Berg et al. (2022).

Neighborhood context in Flint

In the city of Flint, most neighborhoods were built during one of two industrial boom periods during which the General Motors car company grew rapidly: the 1920s and 1950s. As such, Flint is characterized by aging, single-family homes from one of two eras, few multi-family apartment buildings, and an absence of row houses. The community was very much built around the automobile, but a parks plan from the 1920s afforded the city an abundance of greenspace even during its peak population in the 1960s. In subsequent decades, corporate and state disinvestment led to population decline, and this low density environment is now even more sparsely populated. Much informal greenspace is unmaintained or overgrown as a result of a lack of capacity in civic infrastructure. Many blocks which once housed dozens of homes have lost a third to half of their housing stock, and associated businesses, schools, and other institutions have closed as a result (Sadler et al., 2020).

Neighborhood disinvestment and disorder, and specifically high proportions of vacant properties as is common in Flint, have been shown to impact mental health and wellbeing in older children and adolescents. Vacant and unmaintained properties have been associated with higher rates of illness, as well as increased numbers of accidents and injuries (Brisbon et al., 2005; McDonell and Skosireva, 2009). Further, qualitative studies have indicated the significant impact of vacant properties on adolescents' mental health, particularly anxiety and feelings of hopelessness (Teixeira, 2015). Previous studies in Flint have provided similar findings in adults, with vacancy rates related to mental health outcomes, particularly in the context of reduced social ties (Pearson et al., 2019). However, despite indications of the importance of the built environment for development in infancy and early childhood, previous studies have not examined the impacts of disinvestment, measured through vacancy rates and physical disorder, for this age group.

The current study

The current study examined the influence of neighborhood built environment on proximal processes related to infant learning, including parent-child shared reading, parent verbal responsivity (PVR), and parent teaching behaviors, through a secondary analysis of a longitudinal randomized controlled trial (RCT) of an early childhood preventive parent-child intervention. The first aim of this study was to examine direct effects of the built environment on these cognitively stimulating parenting behaviors. The second aim was to determine whether these effects were moderated by parental social support, as previous research in Flint indicated that the built environment was particularly important for adults who lacked social ties (Pearson et al., 2019). This analysis extends previous research on the built environment in childhood by looking beyond physical health outcomes to determine the impact of neighborhood disinvestment on parenting behaviors related to infant learning and development.

Materials and methods

This study was a secondary analysis of data from a longitudinal RCT examining the efficacy of the Video Interaction Project (VIP) intervention in Flint, MI with linkages to geocoded physical environment data. This study was registered with clinicaltrials.gov (NCT03945552), and IRB approval was obtained with the NYU Grossman School of Medicine IRB acting as the single IRB for the study (#s18-01347).

Video interaction project (VIP)

VIP is an evidence-based primary preventive intervention that takes place in pediatric primary care clinics at the time of well-child visits. It aims to reduce disparities in early school readiness and child development through promotion of early relational health. Conceived as an enhancement to Reach Out and Read (Needleman et al., 1991), which provides children's books and anticipatory guidance around shared reading during well-child visits, VIP adds a bachelor's level coach who meets with families one-on-one and video-records the parent and child interacting with a toy or book provided by the program. The coach then reviews the video together with the parent, identifying and reinforcing responsive parenting behaviors and talking with the parent about ways to expand those behaviors. To further support self-reflection and active observation, the interventionist also engages the parent in discussion of their child's development and provides a personalized pamphlet highlighting parent goals for interacting with their child at home. Each VIP session lasts 25–30 min, and participants can receive 14 sessions between birth and age three.

Participants

Infants and their primary caregivers were enrolled in the RCT at the Hurley Children's Clinic within 3 months of their first in-person pediatric visit. For most participants, this occurred within the first 3 months of life [Mean age at enrollment = 1.56 m (1.52)]. Inclusion criteria for children were: Gestational age of 32 weeks or more and a birthweight of at least 1,500 g; singleton birth; no known or suspected significant genetic abnormalities, neurodevelopmental disorders, neuromuscular conditions, or visual/hearing impairment; and no significant neonatal or medical complications. Inclusion criteria for caregivers were: English speaking; had custody of the child; did not have a significant communication impairment; and planned to continue receiving pediatric care at the Hurley Children's Clinic. Families were randomized to receive VIP or care-as-usual.

To date, 78 families have completed baseline and 9-month assessments, of which 68 were currently living in the city of Flint and had neighborhood vacancy rate and observed physical disorder data available, comprising the analytic sample. Descriptive statistics can be found in **Table 1**. Families were primarily low-income and about two-thirds were Black/African-American.

Procedure

Caregivers completed baseline assessments at the time of enrollment and randomization and a follow-up assessment when infants were 9 months of age. At both timepoints, caregivers were interviewed about their family and life circumstances, including sociodemographics, perceptions of their neighborhood, material hardship, stress and mental health, and resilience and self-efficacy. At baseline, caregivers also completed direct assessments of literacy and health literacy. At 9 months, caregivers answered additional questions about their parenting beliefs and behaviors.

TABLE 1 Demographic characteristics and descriptive statistics for the study sample (n = 68).

	Analytic sample % (n)
Female child	50% (34)
First-time parent	35% (24)
Parent high school graduate	82% (55)
Income-to-need ratio < 2[a]	87% (45)
Parent race/ethnicity	
Black/African-American	58% (39)
White	21% (14)
Other	1% (2)
Multiracial	19% (13)
Marital status	
Married	15% (10)
Living with partner	38% (26)
Non-cohabiting partner	15% (10)
Single	31% (21)
Receives public assistance	96% (65)
	M (SD)
Maternal mental health	
PROMIS depression	4.68 (5.27)
PROMIS anxiety	6.14 (5.59)
Perceived stress scale	13.42 (7.08)
Social support/resources	2.71 (0.34)

[a] n = 52.

Measures

Neighborhood built environment

Vacancy rate

Flint's residential landscape is predominantly comprised of single family homes. Vacancy rate was therefore calculated by taking the number of vacant residential parcels (i.e., parcels on which no home sits, where a demolition would have been conducted) and dividing it by the total number of residential parcels, using data from Genesee County, MI.

Neighborhood inventory for environmental typology

The neighborhood inventory for environmental typology (NIfETy) is a valid, reliable, in-person rater-based assessment used to characterize the quality of the built environment along multiple domains including physical features, disorder, violence, alcohol, and other drug exposures (Furr-Holden et al., 2008, 2010). Created in Baltimore, Maryland, it has now been deployed twice in the Flint area (Smart et al., 2021). Based on an assessment of NIfETys at 440 randomly selected block faces throughout the city, we conducted areal interpolation to predict NIfETy values for physical disorder at every location in the city, affording us the ability to append estimated NIfETy scores to every person in our sample living within the city of Flint.

Parent cognitive stimulation

Parent cognitive stimulation in the home was measured via maternal interview using the $StimQ_2$ Cognitive Home Environment ($StimQ_2$; Mendelsohn et al., 2011). The $StimQ_2$ is a standardized interview measure of caregiver cognitive stimulation and includes scales assessing Reading Activities (READ), PVR, Parental Involvement in Developmental Advance (i.e., teaching activities; PIDA), and Availability of Learning Materials (ALM).

The $StimQ_2$ has been validated for use with low-income populations. To ensure accuracy and limit social desirability bias, interview questions include prompts for descriptions/examples and follow-up questions. The $StimQ_2$ has been shown to have high concurrent validity with the HOME Inventory and high internal consistency, with Cronbach's alpha ranging from 0.88 to 0.93 (Dreyer et al., 1996; Mendelsohn et al., 2011; More information can be found at https://med.nyu.edu/pediatrics/developmental/research/belle-project/stimq-cognitive-home-environment). The $StimQ_2$ provides an overall score (range 0–39), as well as scores for subscales mentioned above. For the current study, analyses were conducted for overall $StimQ_2$ scores, as well as for the READ (range 0–18), PVR (range 0–16), and PIDA (range 0–5) subscales of the Infant version of the measure, in order to examine nuances in relations between built environment and parenting behavior.

Social support

Social support was assessed using the Social Resources subscale of the Resilience Scale for Adults. This subscale includes 7 items that ask respondents to rate which of two statements better describes them (e.g., "I can discuss personal issues with no one" vs. "I can discuss personal issues with friends/family members"). The Social Resource subscale has high internal consistency ($\alpha = 0.87$) and concurrent validity with the Tromso Social Intelligence Scale (Friborg et al., 2003).

Covariates

Caregiver education

Caregiver education was included as a continuous variable reflecting years of formal schooling. Education was chosen as a covariate, rather than income, because it's relation to cognitive stimulation has been well-established (e.g., Magnuson, 2007; Zadeh et al., 2010) and because more than 15% of participants in the current study chose not to answer questions related to income. Analyses including income-to-need ratio are included in **Supplementary material**.

Caregiver mental health

An indicator for caregiver mental health was created using confirmatory factor analysis based on scores from three validated scales at infant age 9 months: PROMIS depression, PROMIS anxiety, and Perceived Stress Scale (PSS). Both the PROMIS depression and anxiety scales consist of 8 items that ask the respondent to indicate how often they experienced mood-related symptoms (e.g., "I felt worthless," "I felt uneasy") in the past 7 days. Both scales have strong reliability and high correlations with other validated mental health measures (Cella et al., 2010). The PSS contains 10 items that ask about the frequency with which respondents feel their lives are unpredictable, they are overloaded, or things are beyond their control. A systematic review indicated that the PSS has high internal consistency ($\alpha = 0.60–0.91$) and adequate external consistency ($r = 0.23–0.70$; Lee, 2012).

Randomization group

Group assignment was included as a binary variable, scored 0 (*control*) or 1 (*VIP*).

Analysis plan

Bivariate analyses and multivariate OLS regression analyses were used to examine whether the neighborhood built environment, measured via vacancy rate and NIfETy physical disorder observations, predicted parenting behaviors. Separate regressions were conducted for each measure of built environment. The false discovery rate was used to control for multiple comparisons across measures, and thus q-values, rather than p-values, are presented for individual predictors. All records were geocoded to their precise home location using ESRI's World Geocoding Service, allowing us to spatially join all related built environment data at the exact location where the child lived. While we acknowledge the importance of spatial polygamy in shaping a diversity of exposures (Matthews and Yang, 2013), we also lean on the fact that most exposure takes place close to the home, particularly for young children. In order to examine spatial patterns, geocoded $StimQ_2$ scores were mapped along with smoothed residential vacancy rate areas using ArcGIS. In spatial representations, locations of geocoded addresses were randomly adjusted, or "jittered," and enlarged to preserve confidentiality. Finally, based on previous findings for adults in Flint (Pearson et al., 2019), we also examined whether there was an interaction between the neighborhood built environment and social support in predicting parenting behaviors. Significant interactions were further analyzed using the Johnson-Neyman procedure to identify regions of significance of the conditional effect of vacancy rate and observed physical disorder on parenting behaviors.

Results

Descriptive statistics

Table 1 provides the demographic characteristics and descriptive statistics for the study sample. Approximately one-third of participants were first-time parents, and the majority were from low-income households and identified as Black/African-American or multiracial. Overall, mothers reported relatively few mental health symptoms and moderate levels of social support. Importantly, there were no differences in these characteristics between the analytic sample and the full sample.

As shown in **Table 2**, caregivers engaged in a moderate to high number of cognitively stimulating parenting behaviors, including moderate levels of reading and verbally responsive activities, and high rates of teaching activities. Vacancy rates in residential neighborhoods in Flint are relatively high as compared to other American cities, with a median rate in the current sample of approximately 8%. Rates vary widely across census tracts, however, ranging from nearly 0% in many neighborhoods immediately east and west of downtown Flint to well above 80% in many neighborhoods directly north of downtown.

Bivariate correlations indicated that both vacancy rate and observed physical disorder were significantly associated with $StimQ_2$ total scores, as well as scores on the $StimQ_2$ read

TABLE 2 Descriptive statistics and correlations between primary study variables.

	M (*SD*)	1.	2.	3.	4.	5.	6.
1. Vacancy rate	0.16 (0.21)	–					
2. NIfETy physical disorder	−0.03 (0.58)	0.71**	–				
3. $StimQ_2$ total score	21.47 (6.42)	− 0.38**	− 0.30*	–			
4. $StimQ_2$ read	8.89 (4.23)	− 0.33**	− 0.28*	0.86**	–		
5. $StimQ_2$ PVR	9.28 (2.72)	− 0.24*	− 0.21	0.73**	0.33**	–	
6. $StimQ_2$ PIDA	3.14 (1.26)	− 0.15	− 0.10	0.60**	0.29**	0.53**	–

**$p < 0.01$; *$p < 0.05$.

subscale. Vacancy rate was also associated with PVR, measured by the $StimQ_2$ PVR subscale.

Built environment and parenting

We examined effects of vacancy rate using a series of OLS regression models predicting parent $StimQ_2$ scores and controlling for randomization group, and caregiver mental health, social support, and education (Table 3). For total $StimQ_2$ scores, the model including vacancy rate was significant, [$F(5, 57) = 6.00$, $p < 0.001$], and explained 29% of the variance in $StimQ_2$ scores. Vacancy rate, maternal education, and maternal social support were all significant independent predictors of mothers' cognitively stimulating behavior. Figure 1 demonstrates how vacancy rate itself can be seen to vary spatially, with lower rates east, west, and southwest of downtown, and higher rates to the north and northeast. Further, average $StimQ_2$ scores showed similar variation, ranging from 23.62 (4.97) when vacancy rates were less than 5% to 13.2 (4.92) when vacancy rates were above 55% (Figure 1).

In examining $StimQ_2$ subscales, vacancy rate approached significance in predicting reading and verbally responsive activities ($q = 0.096$ for both), but was not a predictor of parent teaching behaviors.

The model predicting $StimQ_2$ Total scores from NIfETy physical disorder scores and other sociodemographic predictors was also significant and predicted 23% of the variance in $StimQ_2$ scores, [$F(5, 36) = 3.44$, $p < 0.05$]. Although NIfETy scores were a marginally significant predictor of parenting behavior before adjusting for multiple comparisons, it was no longer a significant predictor after adjusting (Table 4). However, both physical disorder and $StimQ_2$ scores vary spatially across Flint. Disorder tends to be highest north of downtown, with the lowest scores running through downtown and to the east and southwest, as indicated in Figure 2. Average $StimQ_2$ scores varied across levels of physical disorder, from 21.85 (6.36) when disorder was high, to 24.20 (6.81) when disorder was low. NIfETy scores were not a significant predictor of any of the $StimQ_2$ subscales.

TABLE 3 Standardized regression coefficients for models predicting parent cognitively stimulating behaviors from neighborhood vacancy rates.

	Total $stimq_2$	$StimQ_2$ read	$StimQ_2$ PVR	$StimQ_2$ PIDA
Vacancy rate	− 0.29*	− 0.23†	− 0.22†	− 0.06
Maternal education	0.42**	0.34**	0.26*	0.32**
Maternal mental health	− 0.13	− 0.06	− 0.17	− 0.24*
Social support	− 0.24*	− 0.08	− 0.30*	− 0.16

**$q < 0.01$; *$q < 0.05$; †$q < 0.10$.

Interactions between built environment and social support

To examine the second aim of this study, OLS regressions with a multiplicative interaction term were used to examine whether the effects of vacancy rate and observed physical disorder on parenting were conditional on parents' levels of social support. For brevity, only significant interactions are discussed here. Results for all analyses can be found in Supplementary material. The interaction between vacancy rate and social support was significant in predicting scores on the $StimQ_2$ Read subscale, $\beta = 2.65$, $p < 0.01$. Johnson-Neyman procedure indicated that the conditional effect of vacancy rate on parent-child reading was significant only when social support was low (Figure 3). The interaction between observed physical disorder and social support was significant in predicting both total $StimQ_2$ scores, $\beta = 3.70$, $p < 0.05$, and $StimQ_2$ Read scores, $\beta = 4.49$, $p < 0.05$. As above, the Johnson-Neyman procedure indicated that the conditional effect of physical disorder on parent-child reading and on parents' cognitively stimulating behavior overall was significant only when social support was low (Figure 3).

Discussion

This study demonstrates the importance of the neighborhood built environment for infant's learning

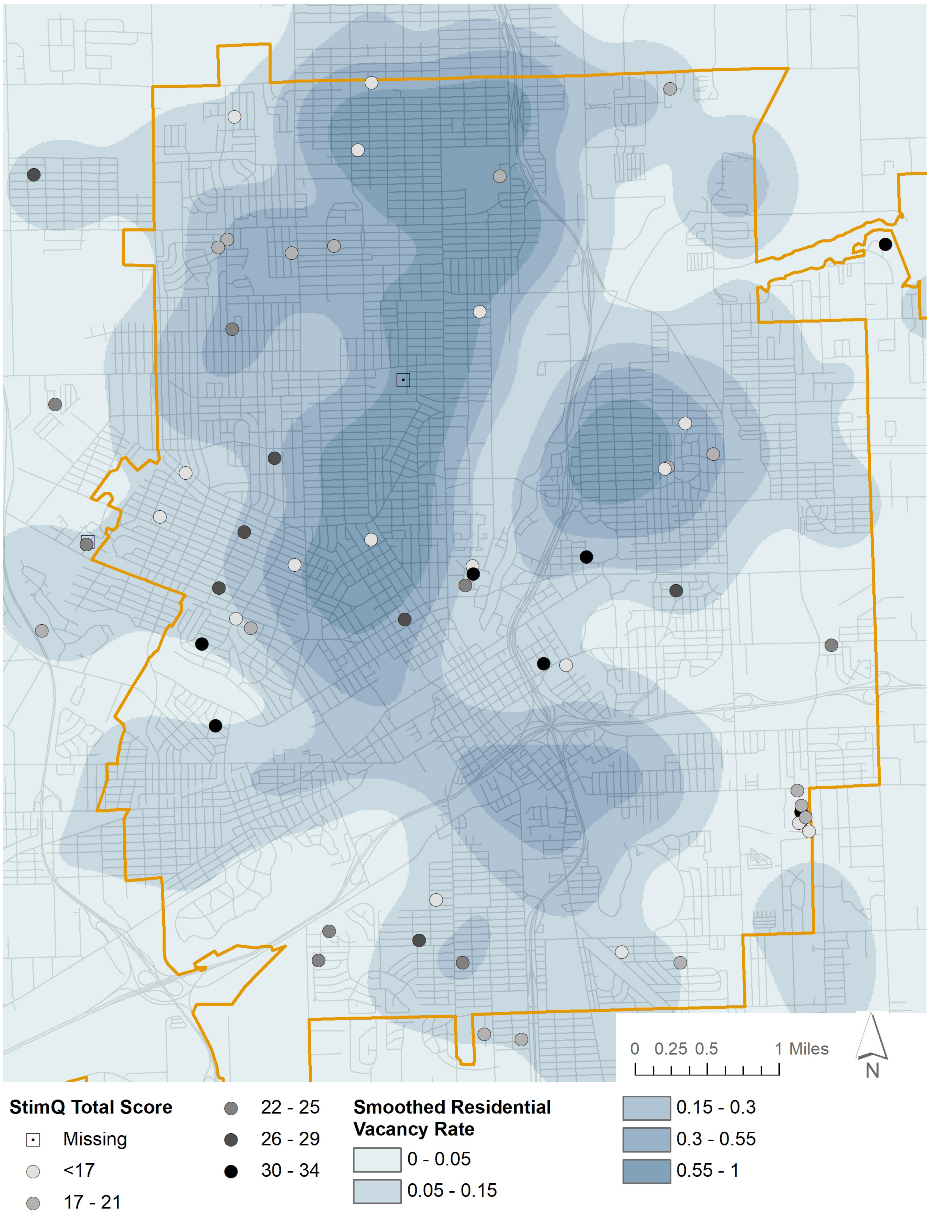

FIGURE 1
Parental cognitive stimulation (StimQ$_2$) and neighborhood vacancy rates.

and development. Specifically, these findings suggest that vacancy rates and physical disorder in an infant's immediate neighborhood are associated with fewer parental cognitively stimulating behaviors, proximal processes that are critical for infants to learn about and understand the world around them. Moreover, these measures of neighborhood disinvestment were particularly salient in the context of low social support, as interactions indicated that they were only predictive when social support scores were low. This mirrors findings of the impact of the built environment on adult mental health in Flint, and underscores the impacts that the neighborhood built environment has on neighborhood residents, both directly and indirectly.

The present results are consistent with prior work demonstrating the impact of neighborhood disadvantage on children's physical, cognitive, and socioemotional development, and on research examining the impacts of the built environment on adult and adolescent physical and mental health. This study extends this understanding by demonstrating that the built environment has associations not just with traditional health outcomes, but for parenting behaviors that are closely tied to infant learning and development. Further, these

TABLE 4 Standardized regression coefficients for models predicting parent cognitively stimulating behaviors from observed physical disorder.

	Total stimq$_2$	StimQ$_2$ read	StimQ$_2$ PVR	StimQ$_2$ PIDA
NIfETy physical disorder	− 0.28	− 0.26	− 0.20	− 0.06
Maternal education	0.42**	0.37*	0.28	0.35*
Maternal mental health	− 0.17	− 0.10	− 0.17	− 0.17
Social support	− 0.25	− 0.09	− 0.32*	− 0.20

**$q < 0.01$; *$q < 0.05$.

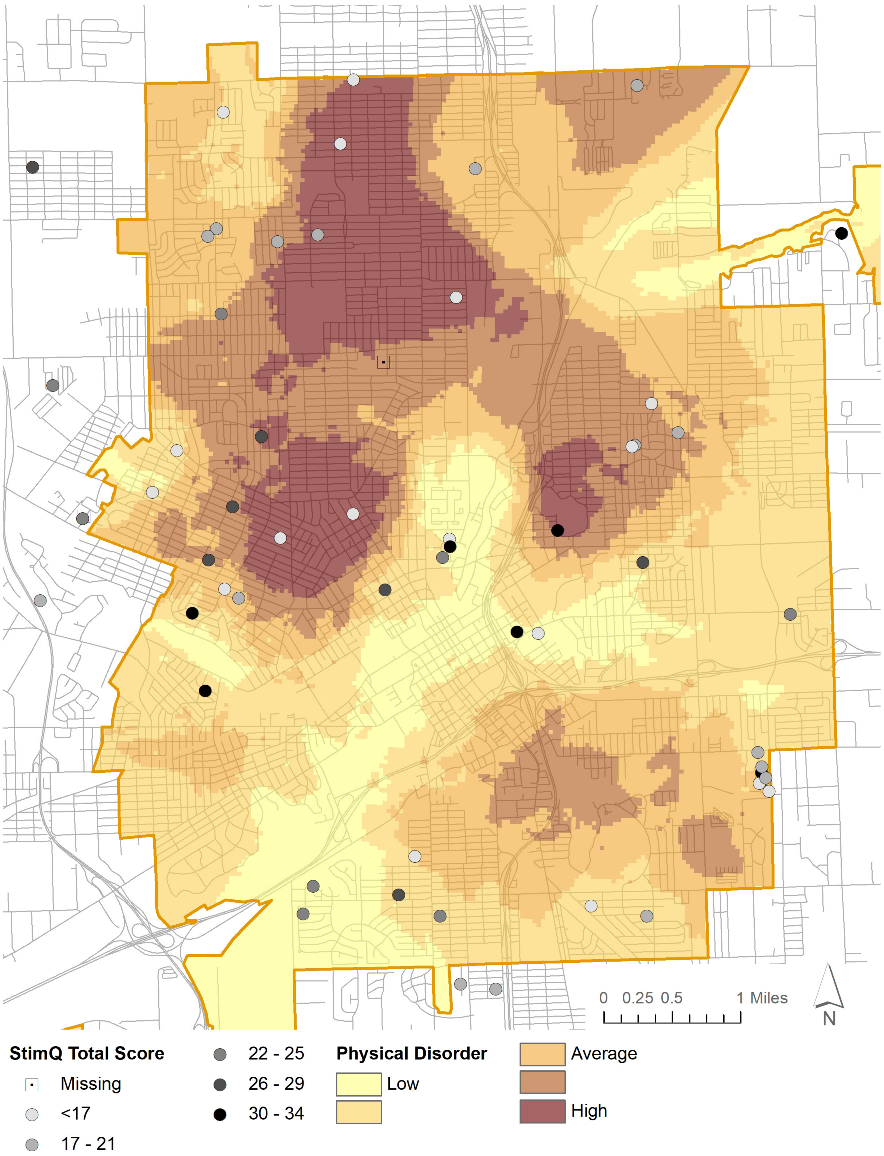

FIGURE 2
Parental cognitive stimulation (StimQ$_2$) and NIfETy physical disorder.

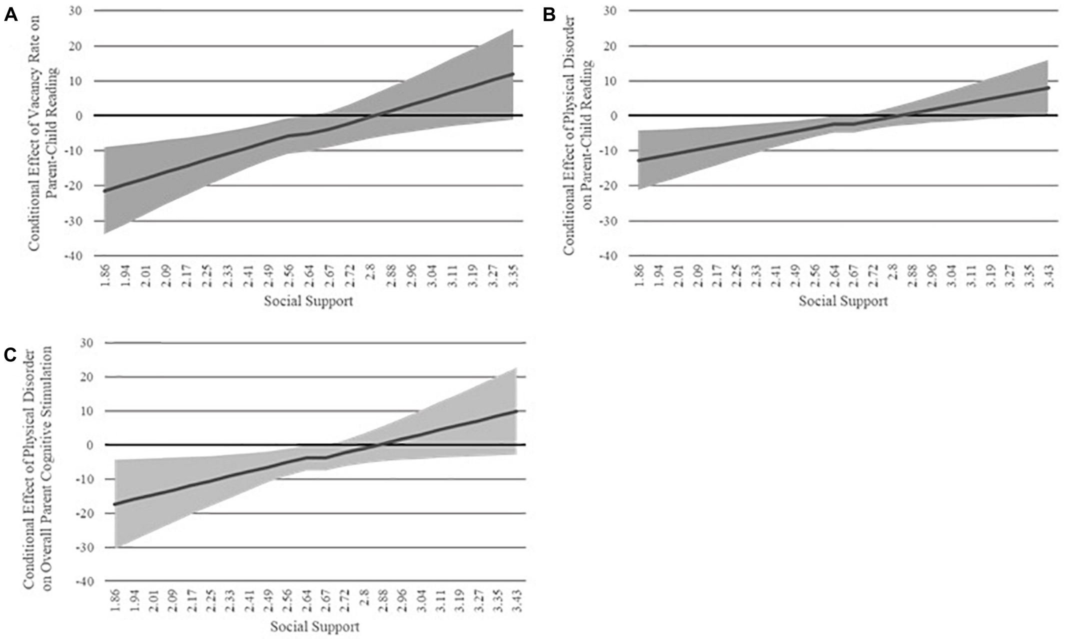

FIGURE 3
Johnson-Neyman plots indicating regions of significance for the conditional effect of **(A)** vacancy rate on parent-child reading, **(B)** observed physical disorder on parent-child reading, and **(C)** observed physical disorder on overall parent cognitive stimulation across levels of social support.

associations were independent of families' income-to-need (see **Supplementary material**). The current findings also extend understanding of the importance of well-designed built environment measures. We used individual-level vacancy rates and objectively measured, individual-level physical disorder scores to determine associations between parenting behaviors and the built environment. This is in contrast to previous work that has mainly relied on subjective, aggregated, or simplified measures of the built environment, such as zip code level data or overall wealth derived from census data. We also report here the approximate (jittered) home locations of participants, both for conceptual understanding and as a proposal as to the possibilities of obtaining and mapping residential data for participants in medical research. Highlighting approximate home locations (rather than aggregating up to ZIP codes or some other unit) also allows researchers to see specific parts of neighborhoods where many people have participated in the program, thus enabling opportunities for geographic recruitment in underserved and well-served neighborhoods alike.

Although the current study was not powered to examine direct impacts of vacancy rates on infant learning, preliminary analyses of a subsample of infants (n = 28) who completed the Mullen Scales of Early Learning at 9 months of age indicated that vacancy rates were associated with lower scores in expressive language ($\beta = -0.49$, $p < 0.05$); this suggests that the neighborhood built environment may impact infants' learning as well as the proximal processes that make that learning possible, and is a promising avenue for future research.

These findings closely connect with our team's prior and continuing work evaluating structural racism in the built environment and how legacies of disinvestment can negatively impact health and wellbeing many decades after the initial land use decision was made to segregate, disinvest, or otherwise create disadvantage in a neighborhood (Rabinowitz et al., 2020; Sadler et al., 2021). The present findings have important implications for clinicians, others working with families in communities that have been under-resourced, and health and urban policymakers alike. Understanding the impact that neighborhoods have on parents and parenting behavior can inform programs and encourage providers to take the full complexity of children's experience at the individual, family, and community level into account. These findings also indicate the importance of policies to address disinvestment at the neighborhood, city, and state levels. Past authors have remarked on the social justice dimensions of dealing with high vacancy neighborhoods in ways that do not further disadvantage the residents therein (e.g., Németh and Langhorst, 2014; Sadler et al., 2020). Historical approaches included urban renewal, which forcibly moved hundreds of thousands of people out of (typically inner-city) neighborhoods, an act carried out in the name of neighborhood improvement or redevelopment (Hyra, 2012). In the contemporary sense, cities are faced with overstrained/underutilized infrastructure, while dealing with the repercussions for residents living in such spaces for decades.

Intergenerational epigenetic effects of living in such weathered neighborhoods have been established in studies of physical health (Forde et al., 2019), and the current analyses provide a first indication that such effects may be important for infant learning as well.

In one series of studies in Flint, authors explored the potential negative implications of conducting some version of right-sizing (or infrastructure removal/down-sizing) on high vacancy neighborhoods (Audirac and Hackworth, 2021; Dewar, 2021; Ehrenfeucht and Nelson, 2021; Ryan, 2021; Sadler et al., 2020). These studies indicated that policies such as those that have been implemented historically achieve neither efficiency or equity for residents, and that community-based approaches are needed. Clearly, the present work has important connections not only to the field of child development and our understanding of proximal processes for infant learning, but also to the growing evidence base on the importance of person-centered approaches to planning for population decline in places such as Flint.

This study is not without limitations. Because of the COVID-19 pandemic, in-person assessments in this study were necessarily limited during the years 2020–2022, leading to a more limited sample size. Further, the city of Flint has experienced both chronic and acute trauma through ongoing disinvestments and the Flint Water Crisis. Given this unique experience, findings may not generalize to other cities or populations. Future research will continue to examine the impact of neighborhood and city disinvestment on cognitive, physical, and socioemotional development among infants and children in Flint, as well as whether disrupted proximal processes, such as the cognitively stimulating parenting behaviors examined here, may, in fact, be modifiable factors, with programs promoting responsive parent-child interactions helping to buffer the effects of a chronic lack of resources in families' communities.

The present findings provide an important first step in developing a comprehensive model of the effects of families' neighborhoods on infant and child development. While much previous research has focused on general socioeconomic factors, such as overall neighborhood wealth, this is the first analysis to our knowledge that uses precise built environment data to examine how vacancy rates and physical disorder—signs of chronic disinvestment—impacts proximal processes critical to infant learning and cognitive development. Continued development of this model is essential to ensuring optimal development during childhood and continued wellbeing throughout the lifespan.

Data availability statement

The datasets presented in this article are not readily available as the data collection is ongoing. Datasets will be available upon completion of primary study aims by request to the corresponding author. Further inquiries should be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the NYU Grossman School of Medicine IRB. Written informed consent to participate in this study was provided by the participants and/or the participants' legal guardian/next of kin.

Author contributions

CC led the writing of the manuscript, with significant contributions from LO'C and RS. AM gave valuable feedback and suggestions. JG and SW provided support during the data collection and writing of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.933245/full#supplementary-material

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Bridging the environment and neurodevelopment for children's health: Associations between real-time air pollutant exposures and cognitive outcomes

Josh Medrano[1*], Natalie Crnosija[2], Richard W. Prather[1] and Devon Payne-Sturges[2]

[1]Department of Human Development and Quantitative Methodology, University of Maryland, College Park, MD, United States, [2]Maryland Institute for Applied Environmental Health, School of Public Health, University of Maryland, College Park, MD, United States

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EDITED BY
Brett Miller,
National Institutes of Health, United States

REVIEWED BY
Amy E. Margolis,
Columbia University Irving Medical Center, United States
Andrew David Ribner,
New York University, United States

*CORRESPONDENCE
Josh Medrano
jmed7@umd.edu

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Research suggests that children's exposure to pollutants may impact their neurocognitive development. While researchers have found associations between air pollutants and cognitive development, these associations remain underspecified. Further, these exposures occur in the context of the built environment and may be exacerbated by local social vulnerability; in this context, individuals may experience a suite of socioenvironmental stressors that lead to increased cumulative risk exposure. In this pilot study, we tested whether real-time-measured personal exposure to $PM_{2.5}$ relates to children's executive function and mathematical skills, outcomes that may predict later mathematical performance, general academic performance and even employment outcomes. We recruited 30 families to participate in two rounds in Winter 2020 and Summer 2021. We collected children's demographic data, as well as data about their living environment. In each round, children carried a small device that collected real-time ambient air pollution data for 3 days; parents logged their children's activities each day. On the last day, children completed cognitive assessments indexing their working memory (n-back), inhibitory control (Go/No-Go), nonsymbolic math skills (dot comparison), and arithmetic skills (equation verification). Overall, 29 participants had pollutant readings from both rounds, and 21 had a full dataset. Nonparametric statistical analysis revealed no significant differences in ambient air pollution and cognitive performance over time, Spearman's rho correlation assessment found that $PM_{2.5}$ was not significantly correlated with cognitive outcomes in R1 and R2. However, the correlations suggested that an increase in $PM_{2.5}$ was associated with worse working memory, inhibitory control, nonsymbolic skills, and arithmetic skills, at least in R1. We used each participant's zip code-aggregated Social Vulnerability Index, which range from 0 to 1, with higher numbers indicating more social vulnerability. Wilcoxon Rank-Sum tests indicated that participants living in higher SVI zip codes ($\geq$0.70; n=15) were not significantly different from those living in lower SVI zip codes (<0.70; n=14), in terms of their $PM_{2.5}$ exposures and cognitive performance in each round. We also found that socioeconomic characteristics mattered, such that children whose parent (s) had at least a Master's degree or earned more than \$100,000 a year had lower $PM_{2.5}$ exposures than children in the other end.

KEYWORDS

air pollution, $PM_{2.5}$, executive function, middle childhood, mathematics

Introduction

A wealth of research shows that children's physical environments influence their psychosocial, cognitive, and socio-emotional development (see Evans, 2006; Ferguson et al., 2013 for reviews). When exposed to built environmental factors such as neurotoxic pollutants, noise, crowding, neighborhood poverty, or substandard housing, children exhibit greater negative externalizing behaviors, lower performance in IQ, cognitive, language, and academic tests, and changes in brain structure, attention, social skills, and anxiety, among others (Evans, 2006; Ferguson et al., 2013; Bennett et al., 2016). Recognition of the substantial vulnerability of the nervous system to environmental effects is growing, especially regarding the developing brain (Bennett et al., 2016; National Academies of Sciences, Engineering, and Medicine, 2020). The focus of this study is on the negative impact of air pollution and social vulnerability of the built environment on cognitive function among school-age children.

A growing body of human studies associate exposure to combustion-related air pollutants ($PM_{2.5}$, polycyclic aromatic hydrocarbons, nitrogen dioxide, black carbon) with adverse effects on brain development, including deficits in intelligence, memory, and behavior (Brockmeyer and D'Angiulli, 2016; Clifford et al., 2016; Xu et al., 2016; Payne-Sturges et al., 2019). Inhaled air pollutants deposit into the respiratory tract and migrate to the central nervous system *via* the olfactory epithelium, the blood–brain barrier, or sensory afferents found in the gastrointestinal tract (Kleinman et al., 2008; Block et al., 2012). Alterations in the central nervous system may directly and indirectly affect the brain, such as through the cardiovascular, pulmonary, and immune systems (Block et al., 2012). Prenatal exposures to chemical exposures can, in the long term, negatively affect regions involved in the regulation of emotion, stress, and behavior (Margolis et al., 2022; Peterson et al., 2022) as well as cognitive functioning (Guxens et al., 2018), as measured *via* blood flow, cortical thickness, tissue microstructure, and hippocampal and cerebral volumes, among others. In children, the blood–brain barrier is more permeable during development than later in life, making childhood a period of extreme vulnerability to toxic exposures (Calderón-Garcidueñas et al., 2008). Air pollution exposures may interfere with neural processes, such as neuronal growth and synaptic processes, which are most active during infancy and in childhood, and such interference may affect brain development (Block et al., 2012). Therefore, children who are exposed to higher amounts of pollution may have impaired cognitive performance relative to those who are less exposed (Allen et al., 2017).

In this study, we are interested in cognitive skills researchers have identified as important during middle childhood for later academic success: executive functions and mathematics. Executive functions are a set of top-down skills that are used to perform goal-oriented, effortful tasks (Diamond, 2013) and include working memory and inhibitory control. Working memory helps store and manipulate information mentally, while inhibitory control helps suppress automatic, predominant responses. While these functions develop differentially across the lifespan (Huizinga et al., 2006), executive functioning, in general, at early and middle childhood have been found to be important for cognitive development and academic achievement, including math and reading (Best et al., 2009; Zelazo et al., 2016). In addition to these cognitive skills, foundational mathematical abilities such as non-symbolic skills, which reflects a perception or sense of number (Feigenson et al., 2013), and arithmetic are influential in predicting academic achievement (Schneider et al., 2017) and success in life and in the workplace (Parsons and Bynner, 1997). These cognitive skills are interrelated: working memory and inhibitory control are significant predictors of mathematical achievement throughout elementary school (see meta-analysis by Spiegel et al., 2021), and executive functions and numerical abilities occupy similar brain regions in the prefrontal cortex (Arsalidou et al., 2018).

We examine these effects in the context of the built environment, in which these effects may be exacerbated by local social vulnerability; in such context, individuals may experience a suite of socioenvironmental stressors that lead to increased cumulative risk exposure (e.g., Payne-Sturges et al., 2019). A broad but very important implication of these findings, both in research and practice, is a greater consideration of the environment (and its impact) on children's cognitive and academic functioning.

Effects of air pollution on cognitive abilities

$PM_{2.5}$ are inhalable fine particles that are 2.5 micrometers or smaller in diameter and are found in ubiquitous sources such as automobile exhaust (US EPA, 2016). Increased exposure to $PM_{2.5}$ and other pollutants have been associated with neurological effects (Payne-Sturges et al., 2019), lower IQ (Porta et al., 2016), developmental disorders, such as autism (Talbott et al., 2015), and reduced white and gray matter in the brain (Mortamais et al., 2019; Beckwith et al., 2020; Cserbik et al., 2020). Importantly, $PM_{2.5}$ has been associated with poorer performance on specific cognitive tests, such as working memory (Alvarez-Pedrerol et al., 2017; Forns et al., 2017; Rivas et al., 2019; Gui et al., 2020) and inhibitory control (Gui et al., 2020; Margolis et al., 2021), as well as academic assessments (Shier et al., 2019; Mullen et al., 2020). The negative impact of air pollution on cognitive functions is well-documented across the lifespan, including infancy, early and middle childhood, adolescence, and adulthood (Lertxundi et al., 2015; Zhang et al., 2018; Margolis et al., 2021; Miller et al., 2021).

Individual-and context-specific factors, such as age, sex, socioeconomic position, and characteristics of the individuals' built environment, may not only affect the amount of pollution to which an individual is exposed but also amplify the adverse effects of those exposures (O'Neill et al., 2003; Thomson, 2019). For example, Clougherty et al. (2007) examined the combined effects of exposure to both socio-environmental (violence) and physico-chemical (air pollution) stressors, finding that among children who experienced more than the median scaled violent event exposure, for every standard deviation increase in NO_2 exposure, there was an associated 1.63 increased odds of asthma; similarly, for children exposed to high stress, there was an increased asthma risk associated with modeled traffic-related pollution exposure (Shankardass et al., 2009). Household income and parent education may indirectly contribute to exposure in $PM_{2.5}$ as they might define household characteristics, such as choices of school and neighborhood (Bell and Ebisu, 2012; Huang et al., 2019). Finally, in a large study of over 10,000 9-10-year-olds, higher residential $PM_{2.5}$ exposure levels were associated with participants who were ethnic minorities (Hispanic or Black) and had parents with a lower level of education and an annual income of less than $49,999 (Cserbik et al., 2020). It is unknown whether these findings are contingent upon the method by which $PM_{2.5}$ exposure is measured. Whereas the aforementioned studies relied upon stationary air sensors, modeled $PM_{2.5}$, and remote sensing to assess $PM_{2.5}$ exposure, none of these studies have used wearable personal air quality monitors that are able to achieve round-the-clock measurement whether the child was outdoors or indoors at a given time.

While a significant literature base has established that air pollution impacts cognitive functioning in children, additional research is needed to understand these relationships. We address several limitations in previous studies, the novel contribution being the use of personal real-time air pollution exposure devices. Previous studies, using longitudinal cohort data, have used aggregate, geographically-matched pollutant exposure as their independent variables, making it difficult to understand the causal pathways that differentially shape poorer neurological outcomes in some children based on their immediate air pollution and social exposure histories. Furthermore, stationary air quality monitors, managed by regulatory entities, cover broad areas and cannot capture instances of the extreme, localized pollution exposure spikes that may be very consequential to children's neurodevelopment. Additionally, computational models that estimate long-term exposure may also mischaracterize personal exposure. Accurately assessing children's exposure to air pollution is intrinsically difficult due to the high spatiotemporal variability of combustion-related air pollution, the unique time–activity patterns of children, including time spent indoors at home and school, in vehicles, and walking, bicycling or playing near traffic sources during peak exposure periods (Brauer, 2010; Cattaneo et al., 2010). Therefore, children may experience high peak exposures over short time periods which cannot be captured by stationary air monitoring. Previous studies linking air pollution to children's development have used a combination of stationary air monitoring and spatial models to estimate long-term exposure. Studies have demonstrated that ambient concentrations and models for air pollutants can mischaracterize personal exposure. This discrepancy is particularly important for children, who are highly susceptible to these exposures due to their ongoing respiratory, cognitive, behavioral and neurological development. Thus, a personal real-time air pollution exposure device may compensate for these limitations and would allow for more correct classification of pollutants and for a more accurate and precise role of air pollution on cognitive and academic outcomes.

Social vulnerability in the built environment

Though individual-level sociodemographic characteristics are relevant covariates when investigating the relationship between air pollution exposure and cognitive performance, neighborhood characteristics may be adjusted for when modeling the relationship between air pollution (PM10 and ozone) and adult's health (Chen and Schwartz, 2009). A tool used to assess neighborhood resilience (or, conversely, neighborhood vulnerability) is the Center for Disease Control and Prevention's Agency of Toxic Substances Data Registry Social Vulnerability Index (SVI), which is a score composed of 15 demographic characteristics for each census tract in the United States using data collected by the US Census and the American Community Survey (Flanagan et al., 2018). This tool's intended use is for evaluating community vulnerability with regard to disaster preparedness—in recent years, it has been used in environmental health studies to capture the vulnerability of the neighborhood in which study participants live.

In summary, we aim to test the effects of real-time $PM_{2.5}$ exposure on cognitive outcomes, while also accounting for demographic and neighborhood characteristics. Our research questions are:

1. To what extent does air pollution associate with cognitive performance? We hypothesize that average $PM_{2.5}$ air pollution exposure over the time period of data collection is negatively and significantly correlated with cognitive performance.
2. Are there differences in air pollution and cognitive performance over time? Based on trends about $PM_{2.5}$

TABLE 1 Demographic breakdown for the full sample (N=30) and the sample with complete data (n=21).

Characteristic	Initial sample		Complete sample	
Child's sex				
Male	14	46.67%	10	47.62%
Female	16	53.33%	11	52.38%
Parent's marriage status				
Married	27	90.00%	19	90.48%
Never Married	2	6.67%	1	4.76%
N/A	1	3.33%	1	4.76%
Child's race				
White	20	66.67%	16	76.19%
Black or African-American	3	10.00%	1	4.76%
Asian	3	10.00%	2	9.52%
Multi-racial, or n/a	4	13.33%	2	9.52%
Child's ethnicity				
Non-Hispanic/Latinx	25	83.33%	19	90.48%
Hispanic/Latinx	4	13.33%	2	9.52%
Age				
7	4	13.33%	2	9.52%
8	10	33.33%	8	38.10%
9	8	26.67%	6	28.57%
10	7	23.33%	5	23.81%
11	1	3.33%		
Annual household income				
Between 20,000-50,000	2	6.67%	2	9.52%
Between 50,000-100,000	4	13.33%	2	9.52%
Above 100,000	23	76.67%	17	80.95%
Parent education				
Some college	2	6.67%	1	4.76%
Bachelor's	10	33.33%	7	33.33%
Master's and/or Professional Degree	18	60.00%	13	61.90%
SVI				
Greater than 0.70	8	26.67%	7	33.33%
Less than 0.70	22	73.33%	14	66.67%

Complete sample consists of participants who had a complete data set.

exposure in the US, participants may be exposed to higher concentrations in the months of January and July (i.e., Winter and summer), and lower concentrations in the late March and mid-October (Zhao et al., 2018).

3. Do demographic and neighborhood characteristics relate to air pollution exposure and cognitive outcomes? Children whose parents have higher levels of education, minority (non-White) status, and greater incomes may be exposed to lower amounts of air pollution compared to their peers (Cserbik et al., 2020). These children may also have better performance in cognitive and academic assessments (Koponen et al., 2007; Dahl and Lochner, 2012; Last et al., 2018).

Materials and methods

This research was designed as a pilot study to investigate the cognitive effects of short-term $PM_{2.5}$ exposures among children ages 7 to 11 years residing in the Washington D.C. metropolitan area. We were interested in how variations in day-to-day exposure to air pollution impact children's cognitive performance on mathematical tasks designed to assess the underlying cognitive processes relevant to numerical cognition. We aimed to conduct the air pollutant exposure assessment campaign across different seasons, specifically the warm and cold periods of the year and measure children's short-term personal exposures to $PM_{2.5}$ using *Flow*, a small, portable device that could be worn or attached to a backpack.

Recruitment strategy and participant selection

Our initial sample consisted of 30 children ages 7 to 11 years recruited *via* a university-run infant and child database, social media postings, and bulletins posted on parks, shopping malls, and other public areas. We excluded children if they had asthma and/or lived in a house where smoking occurred within the home. Recruitment occurred in a large metropolitan area with more than six million people and a median household income of more than $106,000. Additionally, 51% of households in the area had married couples, 51.7% had a Bachelor's degree or more.[1] The race breakdown in the area was 51.9% White, 25.2% Black or African American alone, 10.4% Asian, 7% another single race alone, and 5.6% two or more races.

Twenty-nine children and their parents/guardians completed two rounds, between January 2020 and August 2021, with most of the participation occurring the COVID-19 pandemic. In Round 1, 28 out of 30 participants completed the procedure between October 2020 and February 2021 (the two other participants completed the procedure between January and March 2020). In Round 2, 27 participants completed the procedure between May and August 2021 (one in October 2020). One participant from Round 1 did not participate in Round 2.

The sample of participants with complete data is n=21. Table 1 provides the distribution of both initial and complete sample by parental marital status, education, and household income as well as by children's race, age, and ethnicity, as reported by the parent who completed the baseline demographic survey.

1 www.censusreporter.org

Informed consent procedures

This study was approved by the University of Maryland-College Park Institutional Review Board. As this study's launch coincided with the beginning of the COVID-19 pandemic lockdown, we submitted a revised protocol in accordance with university guidelines regarding the conduct of research during the COVID-19 pandemic. We developed a contactless drop-off/pick-up procedure for the safe distribution of equipment needed for study participation. Parent participant consent and child assent procedure are described below.

Procedure

Figure 1 shows the study procedure. Children completed two rounds of the study, and each round consisted of the same procedure of 3 days of $PM_{2.5}$ exposure monitoring followed by cognitive assessments. On the first day, study personnel delivered the study kit to participants homes. Each participating family received a 13 in. × 8 in. × 4 in. plastic box in which we placed a Flow Air Quality sensor, a Samsung tablet with which the sensors was synced for data collection, Mi-Fi devices to provide the Wi-Fi needed to support these devices and the associated chargers with each device and a laminated series of instructions for use, The tablet was also used for the parents' consent forms, children's' assent forms and baseline survey, all of which were combined into one survey hosted on Qualtrics. Children's daily activities were also noted in a Qualtrics log that was completed each of the 3 days of participation. Also on the Qualtrics platform, the cognitive assessments that children completed at the conclusion of participation were also available on the tablet. During each of the two rounds of participation, this package was dropped off by the research team at participants' homes.

In the first round, the parent completed the consent form and a questionnaire about their household (including demographics) initially, while in the second round, they were asked to provide any updates on household information. Children completed assent forms. After completing the survey, participants were asked to ascertain the connection between the Flow air quality sensor (see next sub-section) and the Samsung tablet. Children wore the air quality sensor on a lanyard provided by the study team over the course of their participation. Children were instructed to keep the sensor by their beds while sleeping. At the end of each day, parents logged their children's activities using a Qualtrics form, which allowed parents to enter a date and identify an activity from a drop-down menu (e.g., Indoors at home, Outdoors at school, etc.) for each 15-min period in a day covering 3 days of the exposure assessment. On the second day, researchers sent an email or text message reminder to parents to remind their children to complete the cognitive tests the following day on the tablets before picking up the equipment. Study personnel communicated with the families by email or text messaging to remind them of the procedures and to check if they had any concerns. On the third day, researchers picked up the equipment after children completed their cognitive tests available on the tablet and their last period of Flow monitoring.

Air pollution personal exposure assessment

We used low cost (~$150/monitor) and commercially available sensors, Flow air quality sensor, from Plume Labs[2] to measure real-time ambient air quality. The Flow sensor measured pollutants (NO_2, VOCs, PM_{10} and $PM_{2.5}$) in the ambient air by air

2 www.plumelabs.com

FIGURE 1
Procedure. Participants completed two rounds. Each round had the same procedure. At equipment drop-off, parents completed a demographics survey, after which the child participants wore the Flow device for 3days. At Day 3, they completed cognitive and math assessments.

being drawn into the device through holes drilled into the body of the device with a small mechanical fan. Particulate matter was measured as the amount of laser-produced light diffracted by particles, and the sensors produced reports of ambient air quality every minute. Calibration of these tools within this sensors is executed *via* machine learning processes enabled through internet connection to the sensor.[3] The accuracy, precision and overall performance of Flow sensors has been investigated by and reported in Crnosija et al. (2022), which found that these sensors are able to detect changes in ambient $PM_{2.5}$ and PM10 reliably. Specifically, a coefficient of determination of 0.76 ($R^2 = 0.76$) was obtained for the relationship between minute-by-minute $PM_{2.5}$ exposure in 32 Flow devices and a Plantower air sensor, indicating how well the average $PM_{2.5}$ measured by the Flow devices predicts that measured by the Plantower air sensor (Crnosija et al., 2022).

For the device to be properly calibrated and collect time-stamped sensor air quality and spatial data, Wi-Fi and GPS connectivity with a companion device (i.e., a Samsung Tablet) were also required. To ensure that Wi-Fi connectivity was maintained throughout a subject's possession of the device, each family was given a Tablet paired with the Flow device and a Mi-Fi, a small Wi-Fi hotspot that provided internet connectivity to the Flow device and the Tablet. Though the Tablet and Mi-Fi were left at home during the child's day, the family would make sure that connectivity among all devices was made upon the child's return home.

The $PM_{2.5}$ data was downloaded from the sensors and time stamps were converted from UTC to EST, accounting for season. Then time-stamped data was aggregated into 15-min increments; this process allowed us to generate averages of $PM_{2.5}$ exposure for every 15 min data was collected. These 15-min averages were then matched to the days of Time Activity Logs, wherein parents used a Qualtrics interface to identify their child's activity at a given time. This coding was completed using Python 3.

Social vulnerability index

Each family was assigned a SVI (a value between 0.0 and 1.0) based on their zip code, with higher values suggesting greater risk of social vulnerability. The value is based on the index provided by the CDC, specifically the overall tract summary ranking variable. Census tracts within the state of Maryland were given an SVI value ranging from 0.000 to 1.000, with 1.000 representing the 100^{th} percentile for extreme social vulnerability and 0.000 representing the 0^{th} percentile for the lowest level social vulnerability, ranked against one another. We use the SVI as a proxy to capture neighborhood effects and the local built environment. We downloaded the 2018 SVI .csv file for Maryland from the CDC SVI web portal and merged it with a tract-ZIP code "crosswalk" file provided by the Department of Housing and Urban Development to "translate" census tracts to ZIP code areas. These two pieces of data were spatially merged using the merge command in Python; the resultant dataset was then exported in an .csv format. As there were multiple entries for each zip code, these values were aggregated by finding the mean by each zip code in the dataset. This dataset was then exported in .csv format and then converted to .xlsx format for merging to the master dataset in Stata.

From this continuous SVI variable, a dichotomous variable was created to categorize participants based on a cutoff of 0.70, representing the upper bound of the scale, with participants with SVI value of more than or equal to 0.70 being coded as 1 (high vulnerability) and those with an SVI of less than 0.70 as 0 (low vulnerability).

Cognitive measures

The child participants completed tasks that measured their working memory (Kane et al., 2007; Antonini et al., 2013), inhibitory control (Kim et al., 2007), non-symbolic comparison ability (Gebuis and Reynvoet, 2012a, b), and arithmetic ability (Jasinski and Coch, 2012). We refer to all tasks collectively as cognitive tasks. The tasks were completed on Qualtrics on a Samsung tablet provided by the research team. Split-half reliabilities were calculated for each block of each task by correlating the first half of the trials for each block to the second half. Figure 2 shows example trials from each task.

Working memory: N-back task

Children were shown a grid of nine 3×3 cm cells, with an 'X' in one of the cells. They are told to press a button if a trial is similar to the previous one (target; i.e., the 'X' did not move) and to not press anything if a trial is dissimilar to the previous one (non-target). Participants were presented with 10 practice trials with feedback and 160 experimental trials, distributed over 2 blocks, without feedback. Each block had 24 targets (i.e., the trial is similar to the previous one) and 56 non-targets, with an option to rest between blocks. Each trial was shown for 1,000 and 1,250 milliseconds, with 500–1,000 millisecond pause between trials. A trial was a "hit" if a participant correctly pressed a target; a trial was a "false alarm" when the participant pressed a non-target. For each participant, a d' statistic, which accounted for hits and false alarms, was recorded. Higher values of d' indicated better working memory. Split-half reliability coefficients in Round 1 were $r(29) = 0.84$ for Block 1 and $r(29) = 0.66$ for Block 2. Split-half reliability coefficients in Round 2 were $r(23) = 0.96$ for Block 1 and $r(23) = 0.92$ for Block 2.

Inhibitory control: Go/No-Go task

Children were shown two types of stimuli, a red or a yellow fish, and were told to press a button when encountering a yellow fish (the Go stimulus) and to not press anything when encountering a red fish (No-Go). Participants were presented with 10 practice trials with feedback and 280 experimental

3 https://plumelabs.zendesk.com/hc/en-us/articles/360009014973-How-does-Flow-work-

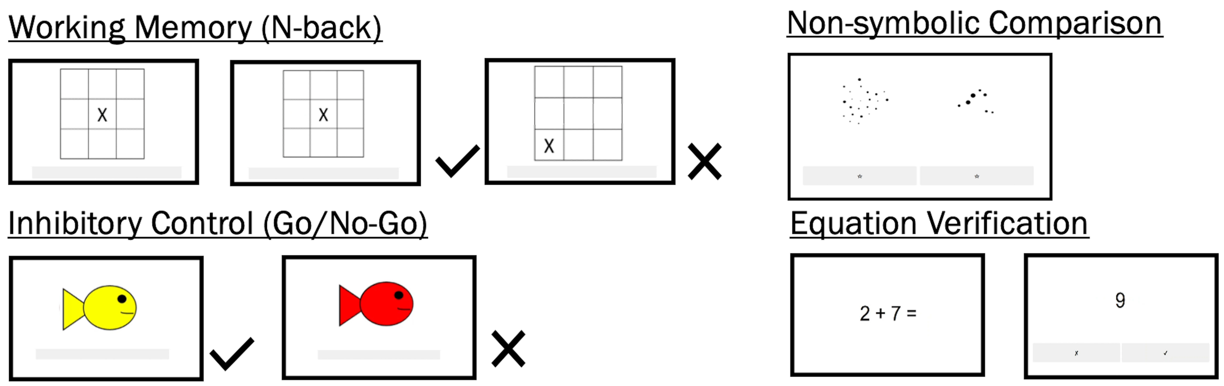

FIGURE 2
Cognitive Tasks. Participants completed four cognitive tasks. See Methods section for the tasks' description.

trials, distributed over 4 blocks, without feedback. Each block had 42 Go trials and 14 No-Go trials, with an option to rest between blocks. Each trial was shown for between 1,000 and 1,250 ms, with 500–1,000 ms pause between trials. For each participant, the number of commission errors (i.e., pressed the button when No-Go stimulus appeared) and commission error rate (i.e., number of commission errors divided by 56) were recorded. The commission error rates were then reversed (1 minus commission error rate), so that higher values indicated better inhibitory control. Split-half reliability coefficients in Round 1 were $r(29) = 0.88$ for Block 1, $r(29) = 0.79$ for Block 2, $r(29) = 0.51$ for Block 3, and $r(29) = 0.87$ for Block 4. Split-half reliabilities in Round 2 were $r(23) = 0.26$ for Block 1, $r(23) = 0.33$ for Block 2, $r(23) = 0.61$ for Block 3, and $r(23) = 0.83$ for Block 4.

Non-symbolic comparison task

Children saw two sets of dots on the screen and were asked to choose which set has more dots. There were 20 unique pairs of dots in total, and these pairs were displayed with varying sizes, such that sometimes, the more numerous have bigger dots (congruent) and sometimes the less numerous have bigger dots (incongruent). There were 4 blocks of 20 trials each; Blocks 1 and 4 were fully congruent; Blocks 2 and 3 were fully incongruent. Participants completed 6 practice trials that were not analyzed. Participants' accuracy was recorded. Split-half reliability coefficients were $r(29) = 0.81$ for Block 1, $r(29) = 0.85$ for Block 2, $r(29) = 0.65$ for Block 3, and $r(29) = 0.45$ for Block 4 in Round 1. Split-half reliability coefficients in Round 2 were $r(23) = 0.41$ for Block 1, $r(23) = 0.47$ for Block 2, $r(23) = 0.30$ for Block 3, and $r(23) = 0.52$ for Block 4.

Equation verification task

Children were shown a single-digit addition equation in two screens, such as that the problem (e.g., '2×2=') is followed by its answer (e.g., '4'). They are told to press a button if the answer was right and to not press anything when the answer is wrong. 112 equations were created, such that 56 problems were presented twice with either the right or a wrong answer. The 56 problems had nonidentical addends and the wrong answer was either 1 or 3 more than the right answer. Participants were first shown practice trials, after which the equations were randomized and shown across 2 experimental blocks. Trials began with the presentation of a warning signal ('+') in the center of the screen for a duration of between 500 and 1,000 ms, after which the problem appeared for 1,500 ms, followed by a correct or wrong answer for 1,500 ms and a blank screen for 1,500 ms. Participants were allowed to respond as soon as they saw the answer, so they had 3,000 ms to respond. Participants' accuracy was recorded. Split-half reliability coefficients in Round 1 were $r(29) = 0.80$ for Block 1 and $r(29) = 0.66$ for Block 2. Split-half reliability coefficients in Round 2 were $r(23) = 0.84$ for Block 1 and $r(23) = 0.71$ for Block 2.

Data preparation

The final dataset consisted of all 30 participants' demographic data, dichotomized SVI values, $PM_{2.5}$ air pollution exposure over 3 days on each round, and performance in the cognitive tasks on each round.

Results

We present our results according to our research questions. Our first two questions explore the extent to which air pollution exposure associate with cognitive performance (Research Question #1) and whether there are differences in air pollution exposure and cognitive performance over time (Research Question #2). We present descriptive statistics, as well as results from Spearman's rho correlation and quantile regression analyses. Our last question concerns whether air pollution exposure and performance in cognitive tasks differ by demographic characteristics, such as sex, income, parental education, and dichotomized SVI (Research Question #3). We present results of Wilcoxon rank-sum tests. Due to the small sample size, we could not infer the distribution of the data and therefore used nonparametric tests for our analysis. Analysis was conducted in Stata 14 (College Station, TX).

Description of $PM_{2.5}$ exposure and outcomes

We first describe round-by-round data and then proceed to examine complete data across both rounds. Table 2 lists the descriptive statistics for the $PM_{2.5}$ and cognitive measures in Round 1 ($n=28$) and Round 2 ($n=23$). Average 3-day $PM_{2.5}$ exposures were below the EPA standard in both Round 1 [*Median* = 3.66, *Mean (M)* = 6.22, *standard deviation (SD)* = 10.32] and Round 2 (*Median* = 3.01, *M* = 3.13, *SD* = 1.29). There was an outlier in Round 1 (i.e., greater than an absolute *z*-score of 3), but we kept that data point in our analysis.

Table 3 lists the descriptive statistics for those with complete data ($n=21$). Similar patterns emerged. Compared to Round 1, these children committed fewer errors in the inhibitory control task (3.05 vs. 2.05) and were more accurate in the non-symbolic (64% vs. 73%) and arithmetic tasks in Round 2 (91% vs. 92%). Wilcoxon signed-rank tests were used to determine whether there were differences between Round 1 and Round 2. The tests revealed a near-significant difference in three-day average $PM_{2.5}$ readings between Round 1 and Round 2 ($Z=-1.96$; $p=0.05$), and no differences in three cognitive measures: working memory ($Z=-1.13$; $p=0.26$), inhibitory control ($Z=-1.52$; $p=0.10$), and arithmetic ($Z=-0.87$; $p=0.39$). The only significant difference from Round 1 to Round 2 is in non-symbolic comparison skills ($Z=-2.24$; $p=0.02$).

TABLE 2 Descriptive statistics in Round 1 (n=28) and Round 2 (n=23).

	Round 1		Round 2	
	Mean	SD	Mean	SD
Flow 3-day Average	6.22	10.32	3.13	1.29
N-back d'	0	1.71	0	1.68
Inhibitory Control Commission Errors	4.36	4.75	2.30	2.62
Dot Comparison	0.64	0.17	0.73	0.13
Equation Verification acc	0.88	0.11	0.91	0.09

N in each round indicates the number of participants that had full data in the given round.

Associations between exposure and outcomes

Table 3 also shows the Spearman's Rho correlations between $PM_{2.5}$ and cognitive measures for those who had completed data across both rounds ($n=21$). The correlations suggested that cognitive measures (working memory and inhibitory control) were correlated with mathematical outcomes. In Round 1, working memory was correlated with arithmetic performance ($r_s=0.81$, $p=0.02$). Inhibitory control was also correlated with arithmetic performance ($r_s=-0.49$, $p=0.02$). In Round 2, working memory was correlated with non-symbolic comparison skill ($r_s=0.46$, $p=0.04$) and arithmetic performance ($r_s=0.50$, $p=0.01$). Non-symbolic comparison skill was significantly correlated with arithmetic ($r_s=0.50$, $p=0.02$).

We conducted quantile regressions to examine whether the associations between $PM_{2.5}$ exposure and children's cognitive outcomes depend on the latter. Quantile regression is a relatively new approach that allows for examination at extreme values of an outcome variable (Koenker, 2005). In separate quantile regressions, we explored the possibility that the $PM_{2.5}$ exposure may affect cognitive outcome at lower quantiles of outcome performance. We started by standardizing all variables (except working memory,

TABLE 3 Descriptive statistics and Spearman's rho correlation coefficients for participants with complete data (n=21).

	Round 1		Round 2			1	2	3	4	5
	M	*SD*	*M*	*SD*	*p*					
1. Flow 3-day Average	7.06	11.81	3.06	1.29	0.05		0.25	0.18	−0.11	0.17
2. Working Memory d'	0.34	1.57	−0.04	1.75	0.26	−0.30		0.21	0.46*	0.53*
3. Inhibitory Control Commission Errors [a]	3.05	3.11	2.05	2.27	0.13	−0.21	0.55**		0.25	0.11
4. Non-Symbolic Comparison	0.64	0.20	0.73	0.13	0.02	−0.11	0.34	0.29		0.50*
5. Arithmetic	0.91	0.07	0.92	0.07	0.39	0.06	0.51*	0.49*	0.05	

Statistical tests consisted only of participants who had full data for both rounds. Round 1 on lower triangle and Round 2 on upper triangle. *p* values are from Wilcoxon signed rank tests of performance between Round 1 and Round 2.

[a]For correlational analysis, we used 1-commission error rate.

*$p<0.05$ and **$p<0.01$.

which was already standardized) and then dividing the outcomes into deciles. Then, each outcome was regressed to $PM_{2.5}$ exposure in each round using the quantreg package in R (Koenker, 2005).

Table 4 lists the regression coefficients. In Round 1, all regression coefficient estimates were negative at the lowest four percentiles, indicating that at the lowest quantiles (i.e., children who performed poorly), children showed negative associations between outcomes and $PM_{2.5}$ exposure. However, the only significant association was for inhibitory control at the 40th percentile, with a coefficient of −0.34, .95 *CI*[−0.95, −0.03]. In Round 2, the patterns were different. For working memory, the lowest quantiles had high, positive coefficients; for inhibitory control, the coefficient of almost every quantile was zero. There was no discriminable pattern for non-symbolic and arithmetic skills and no coefficients were significant.

The role of demographic and neighborhood characteristics

To tease out the associations and account for covariates, we conducted separate Wilcoxon rank-sum tests by round and by demographic variable (sex, income, parental education, and SVI). Table 5 consists of these statistics. For Round 1 ($n=28$), there were no significant differences by sex, income, parental education. For Round 2, we found some significant differences: by income and parental education. Children from households who made above \$100,000 ($n=18$) had significantly less $PM_{2.5}$ exposure than children from households who made below 100,000 ($n=5$), with 2.69 compared to 4.79 ($Z=-3.09$; $p=0.002$). Additionally, those with parents that had master's or professional degree ($n=9$) had significantly less $PM_{2.5}$ exposure ($n=14$) than those with parents who only finished some or all of college ($n=9$), with 2.51 compared to 4.09 ($Z=-3.09$; $p=0.002$). (These results held when for those who only had complete data.) We did not find any other significant differences in other outcome measures or in any demographic category. When comparing those who were assigned an SVI of less than 0.70 and those with SVI of greater than 0.70, we found no differences in $PM_{2.5}$ exposures or the cognitive outcomes in both Round 1 (*ps*: 0.37 to 1) and Round 2 (*ps*: 0.09 to 0.95).

Discussion

In this exploratory study, we sought to examine the associations between children's personal exposure to $PM_{2.5}$, a common air pollutant, and their cognitive abilities, namely working memory, inhibitory control, non-symbolic skills, and arithmetic ability. Our novel contribution to this literature is our real-time measurement of pollution children encounter on a daily basis in their immediate environments. Our findings also mirror extant findings in the extant literature. We highlight three of them.

First, on average, the children in our sample were exposed to $PM_{2.5}$ below the US EPA National Ambient Air Quality Standard (NAAQS). Though it may be perceived that children who experience exposure less than the NAAQS levels are "safe" from the harmful effects of PM2.5, there are several limitations to reliance upon this standard when evaluating these air pollutant exposures with regard to neurocognitive outcomes. The annual standard fails to capture the effects of brief periods of high exposure, or the effects of indoor air pollution, which fall outside of the purview of the EPA. Further, these $PM_{2.5}$ standards may not provide effective

TABLE 4 Quantile regression coefficient estimates and 95% confidence intervals with exposure as predictor.

Rnd	Qtle	Working memory	Inhibitory control	Non-symbolic comparison	Arithmetic
1	0.10	−0.15 [−3.83, 0.53]	0.56 [−8.77, 0.57]	−0.15 [−5.35, 0.47]	−0.23 [−2.71, 0.10]
	0.20	−0.53 [−1.05, 0.36]	−0.23 [−1.56, 0.14]	−0.43 [−1.21, 0.37]	−0.06 [−2.03, 0.45]
	0.30	−0.58 [−1.31, 0.25]	−0.24 [−0.96, 0.20]	−0.30 [−0.90, 0.06]	−0.27 [−1.42, 0.38]
	0.40	−0.51 [−0.95, 0.10]	−0.34 [−0.95, −0.03]	−0.17 [−0.64, 0.05]	−0.33 [−0.54, 0.23]
	0.50	0.02 [−0.86, 0.27]	−0.37 [−0.61, 0.03]	−0.03 [−0.50, 0.02]	−0.29 [−0.42, 0.21]
	0.60	0.09 [−0.78, 0.29]	−0.10 [−0.48, 0.16]	−0.04 [−0.25, 0.52]	−0.11 [−0.45, 0.14]
	0.70	−0.04 [−0.83, 0.53]	−0.12 [−0.52, 0.57]	−0.12 [−0.14, 0.60]	0 [−0.48, 0.10]
	0.80	−0.08 [−0.18, 0.72]	−0.15 [−0.33, 0.53]	−0.17 [−0.20, 0.97]	0.06 [−0.21, 0.22]
	0.90	−0.12 [−0.12, 1.60]	−0.18 [−0.19, 5.45]	0 [−0.26, 1.74]	0 [0, 1.45]
2	0.10	0.39 [−0.06, 0.82]	0 [−0.47, 0.50]	−0.88 [−1.44, 0.63]	−0.12 [−0.73, 0.39]
	0.20	0.46 [−0.39, 0.79]	0.29 [−0.65, 0.61]	−0.15 [−1.05, 0.11]	0.20 [−1.26, 0.29]
	0.30	0.20 [−0.17, 0.92]	0 [−0.79, 0.41]	−0.10 [−0.48, 0.07]	0 [−0.97, 0.50]
	0.40	0.10 [−0.30, 0.64]	0 [−0.29, 0.13]	−0.16 [−0.48, 0.01]	−0.16 [−0.50, 0.36]
	0.50	−0.09 [−0.21, 0.64]	0 [−0.29, 0.19]	−0.26 [−0.51, 0.14]	0 [−0.26, 0.68]
	0.60	−0.01 [−0.18, 0.49]	0 [−0.34, 0.26]	−0.30 [−0.61, 0.26]	0 [−0.28, 0.70]
	0.70	0.03 [−0.21, 0.24]	0 [−0.13, 0.21]	−0.40 [−0.63, 0.33]	−0.08 [−0.34, 0.38]
	0.80	0.03 [−0.11, 0.17]	0 [−0.15, 0.44]	−0.40 [−0.54, 0.35]	0.05 [−0.46, 0.47]
	0.90	0 [−0.21, 0.12]	−0.13 [−0.15, 10.05]	0.11 [−0.61, 0.90]	0.05 [−0.50, 0.23]

TABLE 5 Differences between demographic categories on all measures.

	$PM_{2.5}$ (3-day ave.)[1]	Working memory d'	Inhibitory control[2]	Non-symbolic comparison[3]	Arithmetic[3]
Sex - Round 1					
Female (n = 15)	7.24	−0.208	0.949	0.627	0.849
Male (n = 13)	5.04	0.244	0.921	0.658	0.921
Wilcoxon Test Z	−0.36	−1.04	−0.67	−0.95	−1.78
p value	0.72	0.3	0.5	0.34	0.075
Sex - Round 2					
Female (n = 12)	3.4	−0.137	0.96	0.72	0.88
Male (n = 11)	2.84	0.149	0.98	0.74	0.95
Wilcoxon Test Z	−0.76	−0.40	−1.06	−1.23	−1.81
p value	0.45	0.69	0.29	0.22	0.07
Income - Round 1					
Below 100,000 (n = 5)	4.34	0.92	0.97	0.67	0.9
Above 100,000 (n = 23)	6.63	−0.2	0.93	0.63	0.88
Wilcoxon Test Z	−0.23	−0.99	−1.17	−1.17	−0.33
p value	0.82	0.32	0.24	0.24	0.74
Income - Round 2					
Below 100,000 (n = 5)	4.72	0.2	0.96	0.69	0.87
Above 100,000 (n = 18)	2.69	−0.05	0.97	0.74	0.92
Wilcoxon Test Z	−3.09	−0.23	−0.28	−0.33	−0.60
p value	0.002	0.82	0.78	0.74	0.55
P Education - Round 1					
Bachelor's or below (n = 11)	5.31	0.57	0.95	0.63	0.91
Master's or Professional Degree (n = 17)	6.81	−0.37	0.93	0.65	0.87
Wilcoxon Test Z	−3.09	−0.23	−0.28	−0.33	−0.60
p value	0.21	0.51	0.35	0.89	0.24
P Education - Round 2					
Bachelor's or below (n = 9)	4.09	0.39	0.97	0.69	0.92
Master's or Professional Degree (n = 14)	2.51	−0.25	0.96	0.76	0.91
Wilcoxon Test Z	−3.09	−0.23	−0.28	−0.33	−0.60
p value	0.002	0.73	0.32	0.51	0.47
SVI - Round 1					
Less than 0.70 (n = 20)	4.21	0.1	0.93	0.63	0.87
Greater than 0.70 (n = 8)	11.2	−0.24	0.94	0.66	0.91
Wilcoxon Test Z	−3.09	−0.23	−0.28	−0.33	−0.60
p value	0.38	0.96	0.98	1	0.57
SVI - Round 2					
Less than 0.70 (n = 16)	3.2	−0.03	0.97	0.73	0.9
Greater than 0.70 (n = 7)	2.96	0.06	0.96	0.73	0.93
Wilcoxon Test Z	−3.09	−0.23	−0.28	−0.33	−0.60
p value	0.77	0.95	0.09	0.57	0.81

[1]Median; [2]1 – commission rate; [3]accuracy.

protection against poor neurocognitive health outcomes. We did not have any hypothesis regarding the sample, although we did expect relatively consistent $PM_{2.5}$, given the restricted spatial coverage of our study catchment area, and for the average exposure to be elevated, due to the sample's proximity to a major metropolitan area (as reported by the EPA's EJSCREEN tool).

However, there was a nearly statistically significant decrease in exposure (and a significant improvement in non-symbolic comparison ability) between the first and second round of data collection. Two important factors were the variation in schooling in response to the COVID-19 pandemic and the season in which data collection occurred. For a majority of the children (28 out of 30), the first round occurred between October 2020 and February 2021; the second round (for 28 out of 29 children) occurred between May and August 2021.

Second, children's $PM_{2.5}$ exposure was negatively related to cognitive abilities, though non-significantly. The negative associations correspond to other findings, at least with regard to working memory and inhibitory control (Freire et al., 2010). The current study was the first to include tasks that measured foundational mathematical abilities and found negative associations. However, we found significant associations only in Round 1 (though there was a negative correlation in Round 2). One possible explanation is participants' near-ceiling improvement from Round 1 to Round 2. Another possible explanation is the time of data collection—Round 1 occurred when a majority of schools in the state were in lockdown (and in the winter), while Round 2 occurred when children were going back to schools in-person. Through the quantile regression analysis, we also found the negative associations between $PM_{2.5}$ and cognitive abilities more for those who did poorly on the cognitive tasks. This suggests that participants at the lower end of cognitive outcome distribution represent a vulnerable group, which is consistent with other studies (e.g., Ebisu and Bell, 2012). Given that air pollution exposure as early as before birth influences children at middle childhood and beyond, future research should continue to study its implications for cognitive and academic outcomes across the lifespan.

Third, there were significant differences in exposure by household income and by parent education, with lower $PM_{2.5}$ exposure for children who were in higher household income and had parent(s) with higher education greater than a Bachelor's degree, consistent with other findings (Cserbik et al., 2020). These were important variables to consider because these describe social vulnerabilities and may help earners and their dependents cope with environmental hazards (Cutter et al., 2006). While we did not find any significant differences between participants with SVI greater than 0.70 and those with less than 0.70, it is likely that only some components of the index were more important when considering the effects of air pollution, although more research should be done using the widely-used index.

Limitations and future directions

We were not able to look at whether air pollutant exposure causally affects children's cognitive abilities. However, a candidate causal pathway for socioeconomic differences in neurocognitive development is exposure to environmental contaminants such as air pollution. Racial, ethnic and socioeconomic differences in air pollutant exposures are well documented (Miranda et al., 2011; Tessum et al., 2019; Rubio et al., 2021), and this may be reflected in the brain. For example, Miller et al. (2021) tracked early life stress experiences of 9–13 year olds for two years, as well as volume changes in specific areas of their brains and their exposure to $PM_{2.5}$ in the participants' residential areas. They found a stronger negative effect of $PM_{2.5}$ on brain development for adolescents who had less severe early life experiences. Though in contrast to most studies on respiratory health, it demonstrates that at the neural level, there is an interaction of $PM_{2.5}$ exposure, demographics, and life experiences.

Another limitation is the convenience sampling and the small sample size, as the study was exploratory. Future studies should use a sample representative of families at least in the metropolitan area and should continue to explore the role of demographic factors along with air pollution exposures and other variables that measure the built environment, such as noise pollution (Thompson et al., 2022). Currently, it is unclear whether some factors, such as household income and parent education, are more important than others, such as whether the family lives in a more urban than suburban area. It could be that the air pollution is a mediator of these relations: families with certain demographic characteristics are more likely to live in more polluted areas, and therefore, children in those families have lower cognitive or academic attainment.

Relatedly, increasing the sample size to increase statistical power to identify differences among groups and correlation between measures and providing more research support to participants may be beneficial and may help resolve some of the incomplete data. The incomplete data we had were more due to lack of cognitive scores in some of the participants. Participants completed all measures in a tablet, most of them in one sitting. The estimated time of completion was 1 h and 30 min. While families were given explicit instructions regarding how to complete the tests, researchers can provide more guidance, in the form of proctoring, in the future. It is important to note that the measures are more often used in a laboratory setting.

Prospective researchers may look at other air pollutants, such as PAH, NO_2, and CO_2, and the reliability of the Flow sensor. Future studies may also compare the measurements from the Flow sensor to stationary monitors, as well as measurements in children's exposure when at home in comparison to time when not at home. Implications for practice include using such devices in science classrooms, which may not only teach children about air pollution and its impacts but also encourage actions toward reducing air pollution (Varaden et al., 2021).

Conclusion

The present pilot study aimed to provide evidence for the role of the environment in child development. The results of the study revealed that 1) children's cumulative exposure to particulate matter, $PM_{2.5}$, over 3 days is negatively related to their cognitive abilities, 2) these relations matter greatly for those with poorer cognitive abilities, and 3) socioeconomic characteristics matter.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Institutional Review Board of the University of Maryland College Park. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

DP-S and RP planned this study. NC and JM collected the data, under the supervision of DP-S and RP. JM analyzed the data, with support from NC, who also constructed the project datasets. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Brett Miller,
National Institutes of Health (NIH),
United States

REVIEWED BY
Alfonso Garcia De La Vega,
Autonomous University of Madrid,
Spain
Donghwa Shon,
Chungbuk National University,
South Korea

*CORRESPONDENCE
Yanhua Xu
yanhuaxuedu@foxmail.com

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The mediating effect of geospatial thinking on the relationship between family capital and sense of place

Jianzhen Zhang, Xiaoyu Liang, Ting Su, Xinyao Li, Jiahao Ge, Zhenni An and Yanhua Xu*

College of Geography and Environmental Science, Zhejiang Normal University, Jinhua, China

Few studies have examined how family capital affects the sense of place, and the effect of spatial thinking on the relationship between the two is unclear. This study constructs a mediation model to examine the impact of family capital on sense of place and the mediation effect of geospatial thinking. A total of 1,004 upper-secondary-school students were surveyed using the Family Capital Questionnaire, the Geospatial Thinking Test, and the Sense of Place Scale. The correlation analysis showed that family capital has a positive effect on both sense of place and geospatial thinking. Moreover, there is also a significant positive correlation between geospatial thinking and sense of place. The results of mediation analysis indicated that geospatial thinking plays mediating and buffering roles in the relationship between family capital and sense of place after controlling for gender and residential address. The direct and indirect effects accounted for 73.31 and 26.69% of the total effect, respectively. Specifically, family capital is a significant positive predictor of both sense of place and geospatial thinking, and geospatial thinking partially mediates the relationship between family capital and sense of place. Students from better family backgrounds are more likely to have a better geospatial thinking and sense of place, as well as geospatial thinking promotes the development of a sense of place. Therefore, both family capital and geospatial thinking should be considered when we want to examine and develop individuals' level of sense of place.

KEYWORDS

family capital, sense of place, geospatial thinking, mediating and buffering effects, upper-secondary-school students

Introduction

In recent years, sense of place has gradually become a research priority (Procentese and Gatti, 2019; Bissell, 2021). Numerous studies have shown that a sense of place satisfies people's need for attachment and belonging to a place. Derrien and Stokowski (2014) found that sense of place can improve quality of life. In addition, it can promote pro-environmental behavior, creativity, and academic achievement in geography (Halpenny, 2010; Zhang et al., 2022). Moreover, citizens' worldview and consumerism were also related to sense of place (Ontong, 2018; Rieh, 2020). In other words, a person's sense of place affects their ways of thinking, lifestyle, and physical and mental health (Lengen and Kistemann, 2012).

Many factors influence sense of place. Personal factors include gender, age, social status, education level, and length of residence (Relph, 1976). Environmental factors include those related to social environment [social relations, socioeconomic status, religious beliefs, and participation in activities (Williams and Kitchen, 2012)] and to physical environment [local characteristics of the place, natural environment, building facilities, etc. (Stedman, 2002)].

Home is an important environment for understanding spatial (actual and perceived) influences, so the perception of home is an important element of sense of place research (Maxwell, 2003). Families play a key role in people's health, perceptions, and experiences (Evans and English, 2002; Ackerman et al., 2004; Matthews and Gallo, 2011). Ishizawa (2014) suggested that the higher the education level of a family is, the more it can encourage family members to increase their interaction and connection with the local community. Moskal (2014) found that when the cultural capital of an individual and their family is affirmed in social interactions, that person is better able to integrate into a new environment. In view of the critical role of home on family members' environmental perceptions and emotional experiences (Thornock et al., 2019), it is crucial to understand how family influences the formation of a sense of place.

Researchers have identified geospatial thinking as the basis of sense of place (Gersmehl and Gersmehl, 2007; Bodzin et al., 2014). Research has confirmed that the human brain is capable of processing spatial information and forming spatial cognition, which can contribute to the development of a sense of place (Lengen and Kistemann, 2012). Related studies have demonstrated a possible relationship between family capital, sense of place, and geospatial thinking. According to the family investment theory of Conger and Donnellan (2007), individuals' perceptions and their interactions with the environment are influenced by family socioeconomic status and cultural capital (Ishizawa, 2014; Moskal, 2014; Naik, 2014; Zavala et al., 2018). However, few studies have mentioned the relationship between family capital and sense of place. Similarly, study has shown that the perception of place is influenced by geospatial thinking (Tian et al., 2021). Family parenting style has also been shown to be an important influence on children's spatial thinking (Borriello and Liben, 2018; Clingan-Siverly et al., 2021). However, few studies have focused on the mediating role of geospatial thinking between family capital and sense of place and on the influence of family capital on geospatial thinking.

Thus, the purpose of this study was to verify the relationship between family capital and sense of place as well as the mediating effect of geospatial thinking on this relationship. Understanding the relationship between these three variables is conducive to exploring the influencing factors and the inner mechanisms of sense of place. As well, two frequently reported factors that may significantly influence sense of place—gender and residential address (urban and suburban)—were considered as covariates and controlled in the process. In the following section, the definition of the three constructs, their affecting variables, and the relations between them is presented.

Theoretical basis and hypothesis

Family capital

Family capital, which is derived from social capital theory, refers to family income, education, occupation, and social relationships, and it represents the sum of various types of resources that a family possesses. Bourdieu believed that the forms of capital include social capital, economic, cultural, linguistic, and technological capital (Bourdieu, 1984, 1986; Johnson and Bourdieu, 1993). Coleman (1990) identified three types of family capital—human, financial, and social. Family economic status and the resources and wealth available to the family are defined as financial capital; human capital refers to the cognitive environment provided for children that can facilitate their learning and is usually expressed by the parents' educational attainment; and social capital refers to the resources in the family's interpersonal relationships that can facilitate children's development.

Among the available studies, family socioeconomic status (SES), which is measured by the three indicators of parental education, occupational prestige, and income, reflects the family's economic and human capital (Baker, 2014; Chan et al., 2018). Conger and Donnellan's (2007) family investment model theory and other empirical study suggest that individuals' behavioral, emotional, cognitive, and health status are influenced by family SES (Ackerman et al., 2004). Moreover, these effects begin before birth and continue into adulthood. In the twentieth century, numerous studies demonstrated that children with low SES are more likely to develop psychiatric disorders and symptoms of social maladjustment (Bolger et al., 1995; Lahey et al., 1995; Brooks-Gunn and Duncan, 1997; McCoy et al., 1999). In contrast, higher SES predicts better social cognition, higher independence, and lower aggression in preschoolers (Xie et al., 2020). Second, studies show that children living in poverty have limited access to resources for play and physical activity compared to children from higher-income families (Romero et al., 2001; Tandon et al., 2012), but it has also been noted that low-income families are more inclined to encourage their children to take advantage of their surroundings, while wealthier families are more concerned with opportunities for organized activity (Cottrell et al., 2015). In addition, family socioeconomic status is positively associated with health, and lower SES may lead to a higher risk of physical and mental health problems (Ji et al., 2020). A study shows that high levels of family support are positively associated with children's wellbeing (Moscardino et al., 2021). Choi et al. (2019) found that the risk of suicide is higher for low-income groups than for high-income groups. In general, there is an impact on socioeconomic status on the medical conditions that people experience (Chan et al., 2018). For example, a study confirmed that patients with lower SES were more likely to suffer from ocular trauma (Kousiouris et al., 2022).

In daily life, families with higher SES have more resources to help with personal development (Matthews and Gallo, 2011; Frewen et al., 2015; Wang and Huang, 2021). For example, families with high levels of cultural capital are more likely to pay for remedial education for their children (Southgate, 2013). At the same time, several researchers have demonstrated that students' happiness, health, and satisfaction with life are influenced by family capital (Novak et al., 2018; Kühner et al., 2021; Addae and Kühner, 2022). Conversely, limited family capital can be a barrier to children's development (Chase-Lansdale et al., 2019; Ostroot and Backstrom, 2021).

Notably, researchers have paid particular attention to the impact of family capital on education (Sáenz et al., 2018; Guan and Ploner, 2020; Wang and Huang, 2021; Ren et al., 2022). Li and Qiu (2018) proposed two pathways through which family influences children's academic performance: Parents compete for high-quality educational opportunities, and they change children's study habits through their parenting behaviors and educational support. Gao et al. (2015) showed that factors such as family capital, place of origin, and place of birth significantly affect college students' school performance. Another study confirmed the significant relationship between family social capital and students' reading, math, and science abilities (Lan, 2013).

Various indicators have been used to measure family capital. One of the most common expressions of family capital is SES, which is represented by parents' education, occupation, and income (Warner et al., 1949; Blau and Duncan, 1967; Haller and Portes, 1973; Buchmann, 2002). For instance, the Family Affluence Scale was designed by Currie et al. (1997) as part of the World Health Organization's School Children's Health Behavior in School-Aged Children research project. The survey of home education resources, part of the Trends in International Mathematics and Science Study, includes dictionaries, child-specific desks, computers, and number of books (Third International Mathematics and Science Study, 2019). The Programme for International Student Assessment (PISA) is the largest scale and most influential international education monitoring and evaluation project. Its student questionnaire (Programme for International Student Assessment, 2018) collects information about parent education level, parent occupation, family possessions, and the number of books in the home to analyze the respondent's family environment. The *Family Capital Questionnaire* used in this study was adapted from this questionnaire.

Sense of place

In the 1970s, Tuan and Lowenthal introduced the concept of sense of place (Tuan, 1974, 1975; Relph, 1976; Lowenthal, 1979), arguing that a *sense of place* includes both the inherent characteristics of a place, and the complex connections people have with it. This connection is reflected at the cognitive, behavioral, and emotional levels (Nelson et al., 2020). Since sense of place is a multidimensional concept (Steele, 1981; Stedman, 2002; Hashemnezhad et al., 2013), concepts such as place attachment, place identity, place dependency (Qian et al., 2011; Tapsuwan et al., 2011; Kudryavtsev, 2013), satisfaction (Stedman, 2003; Billig, 2005), community feeling, environment, and health (Williams et al., 2010; Soini et al., 2012) can be considered subordinate concepts of sense of place (Shamai, 1991).

Sense of place is a combination of environment and perception (Tuan, 1975; Smith and Relph, 1978; Brandenburg and Carroll, 1995; Mason and Sack, 1999). Therefore, the formation of a sense of place needs to consider not only the specific location and geographic context, but also the perception of the environment (Massey, 2008). Scholars have argued that sense of place is derived from lived experience and knowledge and is influenced by the external environment (Pred, 1983; Relph, 1997). For example, Soini et al. (2012) believed that sense of place is closely related to the experience of place. Other scholars argue that sense of place and emotion are inseparable (Lanouette, 2022). It has also been shown that urban environmental education is important in developing a sense of place among young people which can make them aware of the ecological value of urban landscapes and thus further promoting awareness of the benefits of protecting and managing the natural environment in cities (Kudryavtsev et al., 2012). In recent years, research in neuroscience has shown that behavioral, physical, perceptual, and emotional elements are all related to the formation of sense of place (Lengen and Kistemann, 2012; Campelo, 2015; McCunn and Gifford, 2021; Wells, 2021), which further demonstrates that sense of place is a combination of environment and perception.

In general, sense of place is influenced by many factors. Personal factors including demographic factors such as residential address (urban and suburban), gender, age, education, and length of residence are included (Hutson et al., 2019; Collins-Kreiner, 2020; Leather and Thorsteinsson, 2021). Environmental factors are related to the physical or social environment. The physical environment generally refers to the unique local characteristics of the place, including physical geography, history and culture, infrastructure and services, and architectural style (Stedman, 2002; Ortiz et al., 2004; Ali, 2019; Dea and Kusuma, 2021). Mohammadi (2021) showed that physical characteristics of urban spaces can affect sense of place by affecting human perception. Factors related to social environment include SES, social ties, holiday celebrations, religion, and welfare (De Bres and Davis, 2001; Mazumdar and Mazumdar, 2004; Williams and Kitchen, 2012).

Quantitative, qualitative, and mixed research methods have been used in the study of sense of place (Shamai, 1991; Jorgensen and Stedman, 2001; Shamsuddin and Ujang, 2008; Amsden et al., 2010; Vannini and Taggart, 2013). Frequently used quantitative methods are constructing models and developing scales. In terms of model construction, Relph (1976) interpreted sense of place factors as a stable natural environment, human activities, meaning, and place spirit. In terms of scale design, the classic local attachment scale was developed by Williams et al. (1992). In addition, Jorgensen and Stedman (2001), who divided place into three dimensions: place attachment, place dependence, and place identity, designed a 12-item scale for sense of place, which we adapted for this study.

Research has shown that a sense of place involves the everyday world and is built-up over both years of residence and involvement in the community (Tuan, 1974, 1975). A study showed that relationships with friends and family, relationships with special places, and length of residence have the most significant impact on sense of place (Hay, 1988), which shows that family and community have an important influence on the sense of place. Most studies have focused on the impact of community context on the sense of place from a meso perspective (Tester et al., 2011; McCunn and Gifford, 2021) and the relationship between community activities and sense of place (Gatti and Procentese, 2021). Zhang et al. (2020) found that urban riverfront landscapes play an important role in promoting residents' sense of place. It has also been shown that students' sense of place is effectively enhanced through participation in community activities (Kim et al., 2020).

At the family level in a micro perspective, the results of one study suggest that sense of place can be transmitted to children through their parents (Hay, 1998). For the individual, the family is a specific environment with unique material conditions and spiritual and cultural atmosphere conditions (Balda et al., 2019; Leto et al., 2019). Family capital can influence individuals' physical and mental health, cognitive development, educational achievement, and future development, and it can influence individuals' perceptions and behaviors. However, few studies have investigated the relationship between family capital and sense of place. After considering the influence of family capital on individuals, we derive the following hypothesis:

> Hypothesis 1: Family capital has a positive predictive effect on sense of place.

Geospatial thinking

For a long time, fields such as cognitive psychology and cognitive neuroscience have focused on the study of thinking and cognition (Holyoak and Spellman, 1993). Thinking, which is based on the perception but transcends its boundaries, is an advanced stage of understanding objective things that evolves with age and experience (Pyle, 1917). *Spatial thinking*, which began with psychological research on spatial cognitive abilities, is the essential and regular understanding of the spatial characteristics of geographic things, phenomena, and laws (Shepard and Metzler, 1971; Bethell-Fox and Shepard, 1988; Carroll, 1993). The definition of spatial thinking is still debated (McGee, 1979; Caplan et al., 1985; Linn and Petersen, 1985; Hegarty and Waller, 2004; Newcombe and Shipley, 2015). The Committee on Support for Thinking Spatially (2006) explained it as "a collection of cognitive skills consisting of spatial properties and concepts, the use of tools for representing spatial information, and tools for spatial reasoning processes" (p. 12). The concept of spatial thinking has attracted attention both in daily life and in education (Schultz et al., 2008; Bednarz and Lee, 2011; Zwartjes et al., 2017; Gagnier et al., 2022).

Geospatial thinking, a kind of spatial thinking specifically for the earth, landscape, and environment, is the basis for people's cognition and understanding of the environment and of space (Gersmehl and Gersmehl, 2007; Bodzin et al., 2014). Bednarz (2011) defined it as the "knowledge, skills, and habits of mind that use representational tools such as concepts, spaces, maps or graphs, and reasoning processes to organize and solve problems." In the beginning, instruments for testing spatial ability, developed by psychologists, provided instrumental support for the measurement of geospatial thinking. However, geographic researchers found that the use of psychological testing methods could cause errors in the assessment of geospatial thinking. This may be due to the fact that people think and reason differently about geographic (large scale) and manipulable (small scale) spaces and that graphical maps to some extent misrepresent the geographic spaces that they show (Mark and Freundschuh, 1995; Lee and Bednarz, 2009; Bednarz and Lee, 2019). Therefore, the development of appropriate methods for measuring geospatial thinking became an important task for geographic researchers. Kali et al. (1997) were the first to add assessment elements that fit the earth sciences to relevant tests. Current research primarily uses the spatial thinking ability test (STAT) developed and designed by Lee and Bednarz (2009), which includes seven question items on map layer overlay that evaluate factors such as selecting an appropriate address, reading topographic maps, locating maps based on verbal descriptions, identifying spatially relevant phenomena, creating contour maps, and distinguishing between types of spatial data (Lee and Bednarz, 2009; Bednarz and Lee, 2019). The *Geospatial Thinking Test* used in this study is adapted from this test.

Several studies have investigated the factors that are related to geospatial thinking (McGee, 1979; Golledge and Stimson, 1997; Gibson, 2014). One discipline related to geospatial thinking is neuroscience, and studies have confirmed the existence of regions of the brain dedicated to different types of spatial thinking (Gersmehl and Gersmehl, 2006, 2007, 2011). Also, neurological factors such as experience, genetics, and hormones are thought to be the source of individual differences in performance on tests of spatial thinking (McGee, 1979). Studies have also confirmed the positive effects on children's spatial thinking development of the use of spatial language and gestures in parent–child interactions (Pruden et al., 2011; Casasola et al., 2020; Clingan-Siverly et al., 2021). As well, personal characteristics and experiences such as age, gender, education, spatial cognition, and home environment are main influencing factors for geospatial thinking (Golledge and Stimson, 1997; Gibson, 2014; Erskine et al., 2020). Studies showed that thinking is always embedded in a specific historical and cultural context and influenced by the resources available in the environment (Gauvain, 1995; Cole, 1998).

Furthermore, the role of education is particularly important. One study found that students engaged in geographic studies had better spatial thinking skills and abilities (Bednarz and Lee, 2019). Teaching equipment and information-technology tools are key to developing geospatial thinking skills (Lee and Bednarz, 2009; Kim and Bednarz, 2013; Ishikawa, 2016; Jo et al., 2016; Xiang and Liu, 2019), and schools in developed areas have relatively more funding to acquire such resources. In summary, the factors influencing geospatial thinking are somewhat related to the family, which leads to the following hypothesis:

> Hypothesis 2: Family capital is a positive predictor of geospatial thinking.

Many studies reported that geospatial thinking was the basis for an individual's perception and understanding of space and the environment (Gersmehl and Gersmehl, 2007; Kerski, 2008; Bodzin et al., 2014). Researcher has shown that specific structures in the human brain are dedicated to processing spatial information (Lengen and Kistemann, 2012). Another study has shown that people with higher spatial-literacy skills form better mental maps of place (Bednarz and Bednarz, 2008). Thus, an individual's way of thinking, consciousness, life processes, social status, and health and wellbeing can also be influenced by a sense of place (Williams, 1998). Thus, we hypothesize as follows:

> Hypothesis 3: Geospatial thinking has a positive predictive effect on sense of place.

Based on the literature and the three hypotheses above, we also propose the following hypothesis:

> Hypothesis 4: Geospatial thinking mediates and buffers between family capital and sense of place.

Figure 1 shows a diagram of the mediation model proposed in the four hypotheses that depicts the relationships between the independent, mediator, and dependent variables and two covariates.

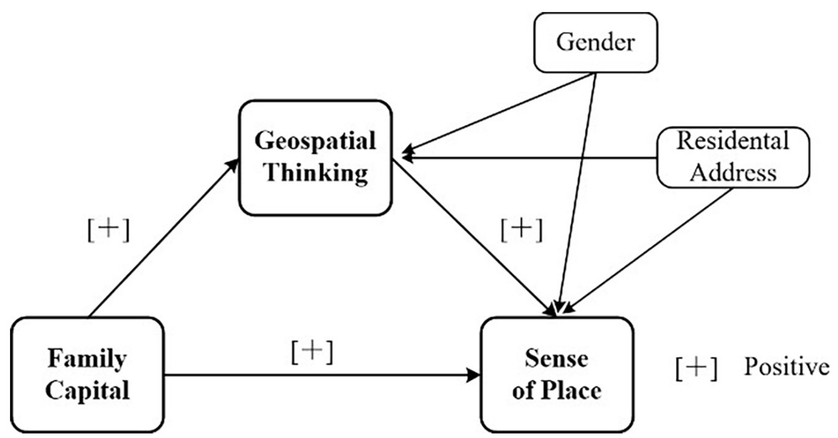

FIGURE 1
Relationships examined in the study.

Materials and methods

Participants and procedures

To develop ideas and hypotheses, we conducted an exploratory focus-group interview in one school before the study design was finalized. Most of the interviewees indicated that they had little knowledge of the outside world and only had a keen sense of the place where they lived. A few of them mentioned that they had different feelings about various places as the result of family travel.

Data collection was conducted in public upper-secondary schools in western China. A total of 1,208 students aged 16–18 completed the survey questionnaire between 10 November and 30 November 2021. Before the students filled out the questionnaires, we explained the study to their parents, head teachers, and geography teachers, and consent was obtained from the students and their parents. During a break between classes, we distributed paper questionnaires to students. We collected the questionnaires after students completed them, and the resulting data were entered into the computer for analysis. After removing any incomplete responses, the number of valid questionnaires was 1,004.

Materials

The questionnaire used to collect data for this study consisted of four sections: demographic information, the *Family Capital Questionnaire*, the *Geospatial Thinking Test*, and the *Sense of Place Scale*. The section on demographic information included gender and residential address. The questionnaires and scales used were adapted from their English-language versions, and we used the back-translation method (Brislin, 1970) to improve the quality of the translation: That is, one researcher translated the instrument from English to Chinese, then another researcher translated the Chinese version to English, and finally, a third researcher compared the three versions (original, translated, and back-translated) of the instrument for consistency between the original English and the translated text to avoid research error caused by translation errors.

Family capital questionnaire

Developed by Programme for International Student Assessment (2018), the *Family Capital Questionnaire* includes three dimensions: parents' education level, parents' occupation, and family belongings. Parental education is scored on a scale ranging from one (completion of primary education) to seven (completion of doctoral education). Parental occupation ranges from 1 (government/authority cadre/civil servant) to 12 (other unclassifiable occupations). Family economic status is determined by the number of items owned, with the corresponding number of points awarded and no points awarded for not owning items. The standardized z values of these six variables were included in the factor analysis based on available studies (Chung et al., 2017). We calculate the total score of household capital by principal component analysis, with higher scores reflecting higher levels of family capital.

Geospatial thinking test

Developed by Lee and Bednarz (2009), the *Geospatial Thinking Test* includes seven dimensions: map layer overlay, evaluating several factors to select an appropriate address, reading topographic maps, locating maps based on verbal descriptions, identifying spatially relevant phenomena, creating contour maps, and distinguishing between spatial data types. It consists of 16 items, such as "If you look along the arrows in 15, which picture in Figure 16 is closest to the landform you see?" "Real-world objects can be represented by points, lines (arcs) and faces (polygons). Please classify spatial data such as urban weather stations, the Yangtze River and its watershed, and the bus route of a primary school." Students' geospatial thinking is scored as one point for a correct answer and no points for a wrong answer. The higher the score, the higher the level of geospatial thinking of the participating students. In this study, the Cronbach's alpha for the scale was 0.695.

Sense of place scale

Adapted from Jorgensen and Stedman (2001), the *Sense of Place Scale* includes three dimensions: place dependence, place attachment, and place identity. It consists of 12 questions, for example, "This place is relevant to me, a reflection of my existence" and "This place is my favorite place." After discussion, some of the item statements were modified to accommodate the language habits and life experiences of students at the secondary-school level. The scale assesses respondents' perceptions and feelings about place on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree). An average score is calculated, and the higher the score, the stronger the sense of place. In this study, the internal consistency coefficient of the scale was 0.688.

Data analysis

SPSS (version 26.0) and the PROCESS plug-in (version 4.0; Hayes, 2021) were used to analyze the data. First, we performed Harman's single factor test to examine common method bias and ensure the validity of the data analysis (Podsakoff et al., 2003). All items in the questionnaire related to the three variables were tested. The results of unrotated principal component analysis showed that 11 factors had eigenvalues greater than 1, of which the contribution to the total variance was 56.162%. The first factor accounted for only 9.117%, which is far below the critical criterion of 40% (Zhou and Long, 2004), indicating that there was no significant common method bias. In other words, the variation between the independent and dependent variables was caused more by difference in the variables than by the methods of data collection and measurement. Following the test of common method bias, descriptive statistical analysis was performed: The mean and standard deviation of each variable were calculated to observe the trend of concentration and dispersion. Then, the Pearson correlation coefficients among the variables were calculated to test the closeness and variation patterns on all variables. Finally, a mediation analysis was conducted using the PROCESS plug-in in SPSS to explore the mediating role of geospatial thinking and further validate the four hypotheses of this study.

Results

Descriptive statistic and correlation analyses

Among the interviewees, 252 (25.10%) were male students and 752 (74.90%) were female students. As for the residential address, 600 students (59.76%) lived in urban areas and 404 (40.24%) in suburban areas. The results of the descriptive analysis of family capital, sense of place, and geospatial thinking are summarized in Table 1.

Pearson's product-moment correlation coefficients were computed to assess the relations among the variables. The results showed (see Table 2) a positive correlation between all three variables. First, family capital had a positive impact on sense of place, with a significant correlation (r = 0.204, p = 0.000). Second, family capital had a moderate positive impact on geospatial thinking, with a significant correlation (r = 0.351, p = 0.000). The positive correlation between geospatial thinking and sense of place (r = 0.238, p = 0.000) was also significant. That is, there was a significant positive relationship between family capital, geospatial thinking, and sense of place in this study.

TABLE 1 Descriptive statistics for the three variables.

Variable	N	M	SD
Family capital	1,004	0.0185	1.7812
Gender			
Male	252	0.1458	1.9182
Female	752	−0.0241	1.7321
Residential address			
Urban	600	0.7876	1.7025
Suburban	404	−1.1237	1.1828
Sense of place	1,004	3.3735	0.4520
Gender			
Male	252	3.3401	0.5021
Female	752	3.3850	0.4338
Residential Address			
Urban	600	3.3890	0.4819
Suburban	404	3.3509	0.4032
Geospatial thinking	1,004	8.4900	2.6780
Gender			
Male	252	8.5400	2.9740
Female	752	8.4700	2.5730
Residential Address			
Urban	600	8.8600	2.7320
Suburban	404	7.9400	2.4980

TABLE 2 Pearson's r for the three variables.

Variables	Family capital	Sense of place	Geospatial thinking
Family capital	1		
Sense of place	0.204**	1	
Geospatial thinking	0.351**	0.238**	1

**$p < 0.01$.

Mediation analysis

To examine the mediating role of geospatial thinking in the relationship between family capital and sense of place, the PROCESS plug-in (version 4.0; Hayes, 2021) was used to perform the mediation analysis with family capital as the independent variable, sense of place as the dependent variable, and geospatial thinking as the mediating variable (Model 4). In accordance with the results of the literature review, gender and residential address were used as control variables. Therefore, students' gender (male and female) and residential address (urban and suburban) were transformed into dummy variables before they were entered in the mediation model.

The results (see Table 3) showed that family capital has a significant positive predictive effect on sense of place (β = 0.0646, t = 7.0192, $p < 0.001$), and the prediction remains significant even when geospatial thinking is entered (β = 0.0474, t = 4.9666, $p < 0.001$). In addition, family capital is a significant positive predictor of geospatial thinking (β = 0.5451, t = 10.4027, $p < 0.001$). Also, geospatial thinking has a significant positive predictive effect on sense of place (β = 0.0317, t = 5.7878, $p < 0.001$). Subsequently, both the direct effect of family capital on sense of place and the mediating effect of geospatial thinking had bootstrap confidence intervals (95%) with no zero between their lower and upper limits (see Table 4). This suggests that, after controlling for gender and residential address variables, family capital can directly predict sense of place and predict it indirectly through geospatial thinking. The direct effect (0.04738) and the mediation effect (0.01725) accounted for 73.310 and 26.690% of the total effect, respectively. That is, family capital is a significant positive predictor of both sense of place and geospatial thinking, and geospatial thinking partially mediates the relationship between family capital and sense

TABLE 3 Results of mediation analysis for the observed variables.

Regression equation		Fitting indices				Significance
Outcome variable	Predictor variables	R	R^2	F (df)	β	t
Geospatial thinking		0.3518	0.1238	47.0902***		
	Gender				0.0308	0.1685
	Residential address				0.1140	0.5995
	Family capital				0.5451	10.4027***
Sense of place		0.2849	0.0812	22.0676***		
	Gender				0.0543	1.7156
	Residential address				0.0815	2.4799*
	Geospatial thinking				0.0317	5.7878***
	Family capital				0.0474	4.9666***
Sense of place		0.2244	0.0504	17.6824***		
	Gender				0.0552	1.7188
	Residential address				0.0851	2.5490*
	Family capital				0.0646	7.0192***

***$p < 0.001$, *$p < 0.05$.

TABLE 4 Total effect, direct effect, and indirect effect among the variables.

Effect	Effect Size	Boot SE	Boot LLCI	Boot ULCI	Relative effect size
Total effect	0.06463	0.0092	0.0466	0.0827	
Direct effect	0.04738	0.0095	0.0287	0.0661	73.310%
Indirect effect	0.01725	0.0036	0.0106	0.0248	26.690%

of place. Our findings about the mediating role of geospatial thinking may be only partial, demanding further attention.

As shown in Table 3, when the association between family capital and sense of place was examined, residential address has an impact on sense of place, while the correlation between gender and sense of place was not significant. There was a significant effect of residential address on the level of sense of place (β = 0.0851, t = 2.5490, $p < 0.05$). Moreover, the effects of residential address on sense of place remained even when geospatial thinking was incorporated into the model. Residential address has a significant effect (β = 0.0815, t = 2.4799, $p < 0.05$), and the association between gender and geospatial thinking was not significant. We found that students from suburban areas have a higher level of geospatial thinking and sense of place. Figure 2 provides a graphic representation of these relationships.

Discussion

Discussion of the results

In this study, we created a mediation model that indicates the relationship between family capital and sense of place, as well as the mediating role of geospatial thinking. The results of this study are congruent with the hypotheses proposed and with previous research.

First, these results agree with Hypothesis 1: Family capital and sense of place were positively correlated. This finding implies that positive environment (Zhang et al., 2020) and positive perceptions and cognitions (Khan et al., 2020) have a facilitative effect on sense of place. Sense of place is the result of the interaction between individual perceptions and the external environment (Relph, 1997, 2007). Therefore, both personal characteristics and external environment can be influential factors in sense of place (Steele, 1981; Kaltenborn, 1998; De Bres and Davis, 2001; Stedman, 2002; Ortiz et al., 2004; Williams and Kitchen, 2012; Eanes et al., 2018; Hu and Chen, 2018; Rast, 2018; Sheybani and Poursoleiman Amiri, 2018). The family, which plays an important role for the individual, both acts as the environment and leads to differences in other factors (Evans and English, 2002; Ackerman et al., 2004; Frewen et al., 2015; Wang and Huang, 2021). In general, individuals with superior family capital are more likely to have a positive emotional response to a given environment. As posited by Tester et al. (2011), the level of attachment to place is higher for those living in high-quality public housing. Conversely, people of low SES are often unable to integrate into and use public spaces, which limits their participation in civic life and diminishes their sense of place in the community

(Trawalter et al., 2021). Therefore, researchers attach great importance to the key role that families play in the development of individuals' perceptions, behavior, and thinking skills (Ogg and Anthony, 2020; Li et al., 2021; Luo and Gao, 2021; Martins et al., 2021).

Second, the results of this study support Hypothesis 2 that family capital has a positive predictive effect on geospatial thinking. Our findings are consistent with the results of similar studies that have demonstrated that superior SES and cultural capital have a positive effect on thinking development (Gauvain, 1995; Cole, 1998; Gearin et al., 2018; Manstead, 2018). This result suggests that family capital promotes the development and improvement of geospatial thinking skills. Studies showed that the use of spatial language and gestures in parent–child interactions has a positive impact on children's spatial thinking development (Pruden et al., 2011; Casasola et al., 2020; Clingan-Siverly et al., 2021). Likewise, family capital influences factors such as educational attainment and home environment. Tomaszewski et al. (2015) found that urban students outperformed rural students on tests of geospatial thinking, and Johnson et al. (2022) demonstrated that children from higher-income families performed better in spatial. However, students from disadvantage have performed less well on spatial tasks (Carr et al., 2018). A possible explanation for this might be that improving students' spatial thinking skills requires the support of various related activities and information technology (Pietsch and Jansen, 2012; Weckbacher and Okamoto, 2012; Xiang and Liu, 2019; Koc and Topu, 2022) and that more affluent or more cultured families are more able to provide for their children (Cottrell et al., 2015).

Third, our findings are in accord with Hypothesis 3 and those studies indicating a significant positive correlation between geospatial thinking and sense of place (Bednarz and Bednarz, 2008; Jepson and Sharpley, 2015). The possible explanation is that both geospatial thinking and sense of place are essentially related to neurological processes, and geospatial thinking is the basis for developing a sense of place (Schinazi and Thrash, 2018; Nicosia, 2019). As posited by Massey (2008), perception influences the formation of sense of place, and geospatial thinking is a tool for perceiving the environment. It has been confirmed that spatial thinking is involved in the formation and development of the sense of place (Hay, 1998; Johnson, 2007; Lengen and Kistemann, 2012). In other words, when interacting with the nearby environment, individuals use geospatial thinking to encode spatial information and thus develop a sense of place (Gifford, 2014; McCunn and Gifford, 2021).

Fourth, our findings are consistent with Hypothesis 4. We found that geospatial thinking mediates between family capital and sense of place, which revealed a pathway for family capital to act on sense of place. First, students with better family capital tend to have better geospatial thinking, which is related to familial influence on individual activities, on life experiences such as language, and on neurological factors such as perception and genetics (McGee, 1979; Ackerman et al., 2004; Cottrell et al., 2015; Frewen et al., 2015; Clingan-Siverly et al., 2021). In addition, geospatial thinking has been proven to be involved in the development of a sense of place. Using functional magnetic resonance imaging, researchers have described the topography of active cortical zones and subcortical formations in the human brain during spatial thought and found specialized structures for processing spatial information (Hölscher et al., 2003; Kentros et al., 2004; Ivanitskii et al., 2015; Kozlova et al., 2016). It has also been shown that the human brain can use spatial information to encode and interpret emotional reactions to meaningful places (McCunn and Gifford, 2018). Overall, the essence of geospatial thinking is a collection of spatial cognitive skills, and relevant research in neuroscience has demonstrated the facilitative effect of spatial cognition on sense of place (The Committee on Support for Thinking Spatially, 2006; Bednarz, 2011; Lengen and Kistemann, 2012). In other words, people with high levels of geospatial thinking in specific environments and activity contexts can more effectively stimulate relevant areas of the cerebral cortex to produce stronger perception and understanding of the outside world, thus positively influencing the sense of place.

Fifth, the results indicate that the effect of gender on geospatial thinking and sense of place is not significant. There are different perspectives in the study of the relationship between gender and geospatial thinking. Some scholars point out that there is no significant difference in geospatial thinking among the different gender, and this is because people have equal exposure to maps that contribute to the development of spatial thinking through smartphones and Internet mapping applications (Bednarz and Lee, 2011; Larianne, 2018). In contrast, others hold the opposite view, with boys outperforming girls in geospatial thinking (Miller and Halpern, 2014; Shin et al., 2016). A possible explanation for this is that androgens promote the ability to process spatial information, so that boys are better at spatial aspects than girls (Núñez et al., 2020). In addition, family socialization influences also play a significant role (Cicognani et al., 2014): Traditionally, male adolescents are more encouraged by parents to become autonomous and make different experiences outside the family than female adolescents, which improved their sense of community environment; women in adulthood, especially those who have kids, get more opportunities to experience the local environment, which helps improve their sense of community (Wood et al., 2013). Conversely, Scannell and Gifford (2010) found that men and women did not differ in their levels of civic or natural place attachment. Indeed, the unequal gender distribution of respondents may have influenced

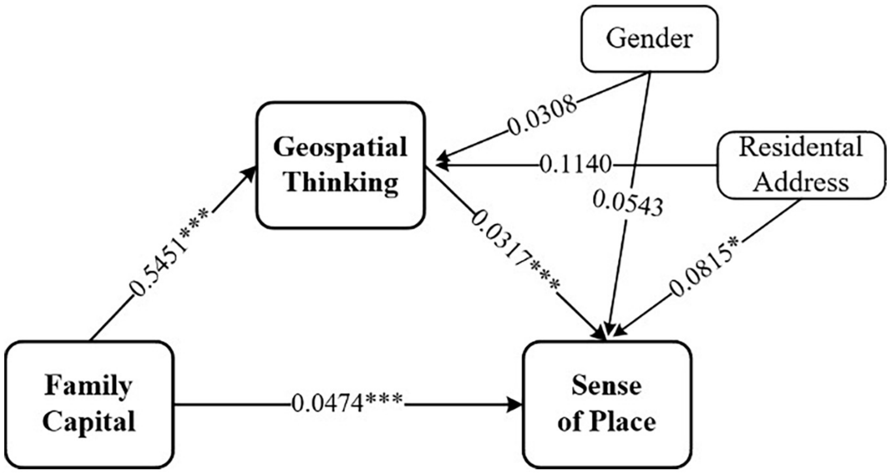

FIGURE 2
Mediation model showing relationships between family capital and sense of place and the mediating role of geospatial thinking. ***$p < 0.001$, *$p < 0.05$.

the results, but the large sample size ensures the reliability of the results of this study. The results also indicated that place of residence significantly influenced the level of sense of place, and students who lived in the suburbs had a higher level of sense of place, which is consistent with the results of other similar studies where place of residence was considered as a factor influencing individuals' level of sense of place (Lim and Barton, 2010). For example, the natural environment of the suburbs can inspire stronger place attachment (Sanecka et al., 2020).

It is worth noting that in this study, geospatial thinking only partially mediates the relationship between family capital and sense of place. The mediation analysis showed that the mediation effect of geospatial thinking was 26.690%. In other words, when geospatial thinking skills are low, higher family capital is still likely to increase sense of place.

Implications

In terms of theoretical implications, this study is unique in linking family capital to sense of place, which deepens the understanding of the impact of family capital on students' sense of place. Furthermore, the mediating and buffering effects of geospatial thinking derived from this study suggest that family capital may enhance geospatial thinking skills and promote a sense of place. In terms of practical implications, the relationships between the three variables proposed in this study may help families, teachers, and other stakeholders gain a deeper understanding of the mechanisms that shape students' sense of place and lay a foundation for them to better help students develop their sense of place.

Limitations and future directions

This study is subject to certain limitations. First, our sample is not population-representative because of the sampling procedures used and, as a result, may not be representative of other regions and time periods assessed. Second, all the participants were from the same region, which may undermine the generalizability of the research findings. Third, the imbalance in the gender ratio of the participants may also hamper the generalization of the results. In future, researchers could use a longitudinal survey design to collect data over a period and recruit participants equally from different schools in different regions, focusing on the impact of city size on the level of geospatial thinking and sense of place, which allows for a deeper understanding of the development of spatial thinking and sense of place in different contexts of time. In addition, they could explore which dimension of geospatial thinking mediates the relationship between family capital and sense of place. Finally, by analyzing the mechanisms underlying the influence of family capital on sense of place and geospatial thinking, we provide a direction for future consideration of how to develop sense of place and geospatial thinking in individual students with a lower level of family capital.

Conclusion

This study explored the relationship between family capital and sense of place and the role of geospatial thinking in mediating between the two. The results indicate that participating upper-secondary-school students with a higher level of family capital had a better sense of place. In addition, students with stronger geospatial thinking skills had a better sense of place than students with weaker geospatial thinking skills. Notably, most variance in sense of place was still attributable to family capital, although geospatial thinking did play a role.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the Ethics Committee of Zhejiang Normal University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

YX and JZ designed the research. JZ, XaL, TS, XnL, JG, and ZA carried out the literature search and data analysis. JZ, XaL, TS, XnL, JG, ZA, and YX wrote the manuscript. All authors have read and agreed to the submitted version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Brett Miller,
National Institutes of Health, United States

REVIEWED BY
Sara Schmitt,
University of Oregon,
United States
Dana Alhasan,
National Institute of Environmental Health Sciences (NIH), United States

*CORRESPONDENCE
Alexandra Ursache
alexandra.ursache@nyulangone.org

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Neighborhood influences on the development of self-regulation among children of color living in historically disinvested neighborhoods: Moderators and mediating mechanisms

Alexandra Ursache*, Rita Gabriela Barajas-Gonzalez and Spring Dawson-McClure

Department of Population Health, NYU Grossman School of Medicine, New York, NY, United States

We present a conceptual model of the ways in which built and social environments shape the development of self-regulation in early childhood. Importantly, in centering children of color growing up in historically disinvested neighborhoods, we first describe how systemic structures of racism and social stratification have shaped neighborhood built and social environment features. We then present evidence linking these neighborhood features to children's development of self-regulation. Furthermore, we take a multilevel approach to examining three potential pathways linking neighborhood contexts to self-regulation: school environment and resources, home environment and resources, and child health behaviors. Finally, we consider how racial-ethnic-cultural strengths and multilevel interventions have the potential to buffer children's development of self-regulation in disinvested neighborhood contexts. Advancing multilevel approaches to understand the development of self-regulation among children of color living in historically disinvested neighborhoods is an important step in efforts to promote equity in health and education.

KEYWORDS

self-regulation, built environment, social environment, neighborhood, early childhood, structural racism

Introduction

Self-regulation includes processes ranging from automatic to effortful regulation of stress physiology, emotion, attention, and executive function and is an important predictor of children's learning and academic achievement (Bull and Scerif, 2001; Raver et al., 2007; Morrison et al., 2010; McClelland and Cameron, 2011; Blair et al., 2015; Blair and Raver, 2015; Blair and Ku, 2022). A number of studies support the integration of these components into a hierarchical integrated model of self-regulation which describes reciprocal and recursive relations among genetic, physiological, behavioral, emotional, and executive function components of self-regulation (Blair and Ku, 2022). Importantly, although these components of self-regulation are separable, they are also intricately linked at any given point in time, as well as across development. As such, direct environmental impacts on more automatic aspects of self-regulation, such as stress physiology, will likely also shape more effortful aspects of self-regulation, such as executive functions. We focus on executive function and emotion regulation as two aspects of self-regulation that develop rapidly in early childhood and that underlie multiple aspects of early school success and later academic achievement (Calkins and Marcovitch, 2010). Furthermore, the inclusion of stress physiology within this model of self-regulation highlights the very important ways in which children's environment can 'get under the skin' to shape other aspects of self-regulation.

Although self-regulation is specified as highly dependent on context, past work has largely focused on family level adversity and poverty-related risk. A small literature has begun to investigate self-regulation in neighborhood context. To guide this area of inquiry in the service of creating more equitable opportunities for children to thrive, more work is needed to conceptualize self-regulation as situated in neighborhood contexts (Blair and Ku, 2022). Most work examining relations of neighborhood disadvantage to child development has focused on neighborhood concentration of poverty (Minh et al., 2017). For example, evidence suggests that moving out of high poverty neighborhoods, as compared to remaining in these neighborhoods, is associated with increases in self-regulation (Roy et al., 2014). Composite indices of disadvantage have also been used to demonstrate links to children's stress physiology (Finegood et al., 2017) and to differences in functioning of brain regions underlying self-regulatory processes (Gard et al., 2021). On the one hand, composite indices or profiles capturing co-occurring risks can be highly useful for comparing across different neighborhoods because they condense the complex exposures encompassed by neighborhoods (Messer et al., 2006; McCoy et al., 2022). On the other hand, however, understanding the ways in which specific aspects of the built and social environments may influence children's self-regulation can serve to highlight new opportunities for enriching neighborhood contexts to support the development of self-regulation.

We propose a conceptual model of self-regulation development in neighborhood context which centers children and families of color who are living in historically disinvested neighborhoods (Figure 1). Our model focuses on early childhood as a time of high plasticity in the brain areas underlying self-regulation and rapid development of self-regulatory systems from more automatic to more effortful processes (Carlson et al., 2005; Garon et al., 2008). Our approach draws on theoretical foundations from Garcia-Coll's integrative model of child development (Garcia-Coll et al., 1996) and Rogers' M(ai)cro conception of development (Rogers et al., 2021) to emphasize the ways in which the structures of systemic racism and social stratification hinder children's development. These macro-level forces shape the neighborhoods in which children of color live, children's exposure to neighborhood built and social environments, and thus their daily experiences which intimately influence the developmental process of self-regulation. Most of the literature to date, however, has not incorporated an adequate examination of these structures and how they create inequality across neighborhoods (Minh et al., 2017). Models that attempt to situate self-regulation in the neighborhood context while largely ignoring structures of historical disinvestment (e.g., Maniar and Zaff, 2011) have the potential to harm communities of color and distort the role of self-regulation in improving health and educational equity. For example, a model that does not mention the enduring impacts of racism but conceptualizes the burden of inequities in underserved neighborhoods as in part resulting from lower self-regulation of individuals (Maniar and Zaff, 2011) may perpetuate a narrative in which communities of color are blamed for the social, economic, and health disparities that they experience.

Drawing on Rogers' M(ai)cro conception of development (Rogers et al., 2021) we take as our starting point the macrosystem structures of racism and social stratification, which have led to high concentrations of families of color with low incomes living in neighborhoods faced with a number of built and social environment risks. The built and social environment are hypothesized to impact children's self-regulation development directly and through multilevel mediating pathways including classroom environment and resources, home environment and resources, and children's health behaviors. Drawing on Garcia-Coll's integrative model (Garcia-Coll et al., 1996), we emphasize that neighborhoods also consist of internal community resources that can support or hinder child development. Racial-ethnic cultural strengths of families of color may buffer neighborhood risk by promoting neighborhood social support and strengthening protective family processes. Additionally, interventions at multiple ecological levels can support communities in changing neighborhoods or buffering the impacts of neighborhood risk factors on child self-regulation.

Structural racism and social stratification create historically disinvested neighborhoods

Structural racism and social stratification have influenced the creation of historically disinvested neighborhoods and have led to high concentrations of low-income families of color living in these areas (Cashin, 2004; Faber, 2020). As a prime example, "redlining"—"the practice of denying borrowers access to credit based on the location of properties in minority or economically disadvantaged neighborhoods" led to disinvestment in these neighborhoods (Mitchell and Franco, 2018 p 5). Several studies have utilized the "Residential Security" maps drawn up in the 1930s by the Home Owners' Loan Corporation, an agency of the federal government, to quantify the enduring impacts of redlining.

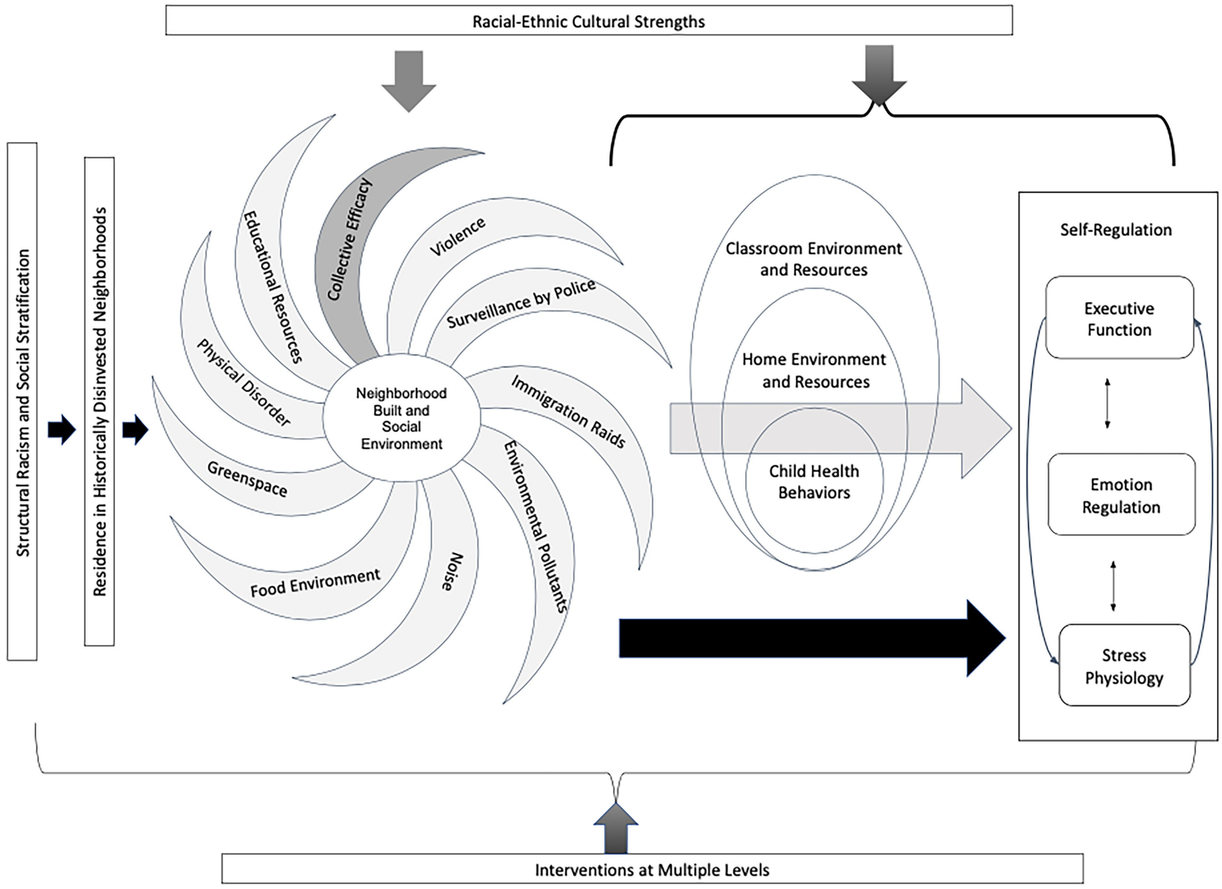

FIGURE 1
Conceptual model of built and social environment influences on the development of early childhood self-regulation in historically disinvested neighborhoods.

On the HOLC maps, neighborhoods were rated according to their perceived level of mortgage lending risk. These evaluations were based on a number of characteristics, but a major factor was the race and ethnicity of residents in the neighborhood (Meisenhelter, 2018). Although there is some debate as to the exact use of these maps, these maps clearly represent local-level lending decision makers' collective understanding about neighborhood risk (Mitchell and Franco, 2018). This conflation of race with lending risk led to a self-reinforcing cycle of beliefs in racial hierarchy, unequal investment in neighborhoods, white families moving to suburbs while Black families remained crowded in inner city areas, and in turn increases in suburban property values coupled with deteriorating city neighborhoods (Faber, 2020). This cycle continues today as homes in white neighborhoods are appraised higher than homes in Black and Latinx neighborhoods, with some estimates indicating about a 20% gap (Perry et al., 2018; National Fair Housing Alliance, 2022).

Today, the majority of areas that were identified as most risky on the HOLC maps remain low-to-moderate income and minority neighborhoods (Mitchell and Franco, 2018), and redlining continues to have enduring effects on these neighborhood environments (Meisenhelter, 2018; Schwartz et al., 2021). For example, over 80 years later, neighborhoods that were redlined have less greenspace (Nardone et al., 2021), greater density of tobacco retailers (Schwartz et al., 2021), are more likely to be "food deserts" with lower access to supermarkets and higher reliance on convenience stores (NYLSRJP, 2013; Zhang and Ghosh, 2016), and have higher rates of gun violence (Jacoby et al., 2018). Furthermore, the enduring impacts of racism can be seen when looking across a broad swath of neighborhood factors that support child health and development. For example, the Child Opportunity Index (COI) is a comprehensive measure that captures 29 neighborhood factors shown to predict child outcomes. In examining Child Opportunity Scores by race across the 100 largest metro areas in the United States, the score for white children was more than three times the score for Black children and more than two times the score for Latinx children (Acevedo-Garcia et al., 2019). Additionally, the HOLC rating of the neighborhood in which children grow up has causal and economically meaningful impacts on their outcomes as adults (e.g., household income, credit scores, and likelihood of living in a high-poverty neighborhood; Aaronson et al., 2021). In addition to redlining, the impacts of systemic racism likely constrain neighborhood residence for families of color in less well documented ways. For example, undocumented immigrants have reported choosing to live in majority Black or Latinx neighborhoods rather than in higher opportunity white neighborhoods because law enforcement patrols in white neighborhoods are perceived to target Latinx individuals, specifically those who are undocumented (Asad and Rosen, 2019). Thus, structural racism and poverty have led to the enduring segregation of children of color into neighborhoods plagued by built and social environment risks.

Linking neighborhood social and built environments to children's self-regulation

The small literature on self-regulation in neighborhood contexts supports a role for both the built environment and social environment in shaping components of child self-regulation. We build on a model of self-regulation, which highlights the bi-directional relations between more effortful aspects of self-regulation such as executive function and more automatic processes including stress physiology and emotion regulation (Blair and Ursache, 2011; Blair and Ku, 2022). Stress physiology involves biological regulation through the hypothalamic–pituitary–adrenal (HPA) axis, the parasympathetic nervous system (PNS), and the sympathetic nervous system (SNS; Holochwost et al., 2021). Automatic forms of attention emerge in infancy, and as children develop, more effortful forms of attention emerge, setting the stage for effortful aspects of emotion regulation and executive functions. Emotion regulation is defined as a set of contextually influenced, dynamic processes that modulate emotion (Eisenberg et al., 2004). Executive functions are cognitive skills that support goal-directed behavior through organizing, planning, and problem solving (Blair and Ursache, 2011).

Emerging work links multiple aspects of neighborhood context to children's self-regulation, but much of this work has focused on the ways in which neighborhood risk factors undermine development of self-regulation with less attention to the possibility that neighborhood factors may also be promotive (Hyde et al., 2022). We highlight three pathways by which neighborhood context may confer risk for self-regulation as well as was the role of neighborhood protective factors in supporting self-regulation. A prominent pathway involves aspects of the neighborhood that impair self-regulation by directly affecting the brain and interconnected biological systems in a young child's developing body. Neighborhood factors that operate through this pathway include increased exposure to toxicants (e.g., air pollution) or deprivation of access to the physical inputs necessary for healthy growth and development (e.g., nutrient dense food; Mikkelsen and Chehimi, 2007; Block et al., 2012; Jones et al., 2014; Bryant et al., 2020; Jackson et al., 2021).

Furthermore recent conceptualizations of early childhood social and cognitive adversity have considered risk along two dimensions—threat and deprivation—with specific predictions of how each type of risk may impact development (Sheridan and McLaughlin, 2016). Threats are defined as those aspects of the environment which may cause or can be perceived as potentially causing harm to children's physical or psychological well-being. In the neighborhood context, possible threat exposures likely include crime, noise, physical disorder (e.g., dilapidated buildings), surveillance by police, and immigration raids. Exposure to threat can have direct impacts on children's self-regulation. Threat leads to activation in stress response systems which over time can lead to dysregulation in these physiological systems, resulting in alterations to more automatic aspects of self-regulatory processes.

Deprivation involves children not receiving inputs that are necessary to support healthy growth and development. At the neighborhood level, children may experience deprivation because they do not receive adequate cognitive stimulation in neighborhoods that lack high quality educational resources, such as libraries, museums, childcare, or schools (Hyde et al., 2022). Exposure to deprivation is thought to more directly impact the most effortful aspects of self-regulation such as executive function by not providing the social or cognitive stimulation necessary to develop these higher level cognitive processes. Importantly, however, the integrative model of self-regulation describes how these automatic and effortful processes are linked and thus alterations to one component of self-regulation will likely lead to alterations in the other components as well (Blair and Ku, 2022).

Although less well studied, neighborhood level promotion of self-regulation may occur in the absence of risk factors or through the presence of protective factors—positive social and built environment resources—such as collective efficacy and greenspace. These protective factors may support self-regulation independently of neighborhood risk, or their effects may depend on the level of risk in the neighborhood. In line with the stress buffering hypothesis proposed by Luthar et al. (2000), these promotive factors may buffer children from the impacts of neighborhood risk factors on self-regulation by attenuating children's experience of stress. Alternatively, however, the "overwhelming-risk" hypothesis (Luthar et al., 2000; Li et al., 2007) describes how high levels of risk can wash out the impact of protective factors.

Social environment and self-regulation

Collective efficacy

Collective efficacy encompasses social cohesion (mutual trust among neighbors) and informal social control (willingness of neighbors to intervene in the service of shared goals; Sampson et al., 1997). Contexts of concentrated neighborhood disadvantage undermine the development of collective efficacy through limited opportunities for homeownership, decreased residential stability, and resource deprivation (Sampson et al., 1997). Importantly, although social cohesion is likely necessary for collective action through social control, it is not sufficient. The physical and psychological toll of resource deprivation can undermine the development of collective action even when personal connections are strong (Sampson et al., 1997). Several studies of child outcomes in the context of collective efficacy suggest that collective efficacy may impact children's self-regulation. In children, collective efficacy has been shown to be related to better mental health (Xue et al., 2005) and behavior problems (Ingoldsby et al., 2006; Kohen et al., 2008). This relation between collective efficacy and both externalizing and internalizing behavior problems is evident as early as 3 years of age (Ma and Grogan-Kaylor, 2017). Other work has identified trajectories of neighborhood cohesion and their relation to mental health and behavior in adolescence (Kingsbury et al., 2015). Increasing neighborhood cohesion over the course of childhood was associated with lower hyperactivity and indirect aggression in adolescence. Growing up in neighborhoods low in social cohesion was associated with anxiety and depressive symptoms. Declines in neighborhood cohesion were also associated with hyperactivity. Neighborhood support has also been associated with parent perceptions of whether their school-aged children are flourishing as defined by curiosity about learning, resilience, and self-regulation (Kandasamy et al., 2018). Future work is needed to clarify whether collective efficacy impacts self-regulation specifically and whether these impacts are direct or mediated through home and school processes (detailed in the Mediating Pathways section below).

Furthermore, although not well studied in relation to children's self-regulation, some evidence suggests that collective efficacy may be an important moderator of neighborhood risk factors (Hyde et al., 2022). For example, adolescents' perceptions of social cohesion in their neighborhood moderated the association of neighborhood structural disadvantage (i.e., index of neighborhood characteristics) with adolescent depressive symptoms (Dawson et al., 2019). Without considering social cohesion as a moderator, neighborhood structural disadvantage was associated with greater depressive symptoms. Social cohesion, however, moderated this relation such that at high levels of social cohesion, higher neighborhood structural disadvantage was associated with lower depressive symptoms suggesting that at high levels of social cohesion, neighborhood structural disadvantage may not negatively impact adolescent depressive symptoms. Similarly, high neighborhood collective efficacy has been shown to buffer impacts of exposure to gun violence on adolescent's functioning of corticolimbic circuits that support socioemotional processing (Gard et al., 2022). Positive social processes in the neighborhood have also been shown to buffer the association between neighborhood disadvantage and increased amygdala reactivity to threat (Suarez et al., 2022). More work is needed to understand the potential of collective efficacy to buffer the impact of social and built environment risks on children's self-regulation.

Violence

A number of studies demonstrate that school-age children and adolescents living in historically disinvested neighborhoods experience serious forms of violence in their communities, which has broad negative impacts on multiple aspects of their health and development (Attar et al., 1994; Gorman-Smith and Tolan, 1998; Kliewer et al., 1998; Linares et al., 2001; Farver et al., 2005). Young children are also exposed to many different forms of neighborhood violence, including property crimes, assaults, and shootings (Taylor et al., 1994; Farver et al., 1999; Finkelhor et al., 2015). Theory suggests that early exposure to violence can shape multiple aspects of self-regulation including stress physiology, emotion regulation, and executive function (McCoy, 2013). Empirical work demonstrates that neighborhood violence shapes children's attentional processes, and impulse control (Sharkey et al., 2012; McCoy et al., 2015b, 2016). In one study, children living in neighborhoods characterized by high levels of crime exhibited a more vigilant pattern of attention than children from lower-crime neighborhoods (McCoy et al., 2016). Similarly, living in close proximity to recent violent crime was associated with vigilant patterns of attention for children with low trait anxiety, whereas among highly anxious children, this exposure was associated with avoidant patterns of attention (McCoy et al., 2015b). Among preschool aged children, the occurrence of a homicide near their home in the past week was associated with lower levels of attention and impulse control as observed by research staff conducting one on one assessments with children in the school setting (Sharkey et al., 2012).

Surveillance by police

In the past 20 years, many police departments have adopted an approach of "proactive policing" which aims to deter criminal behavior through increasing police presence and stringently enforcing laws pertaining to minor crimes (Geller and Fagan, 2019; Justice, 2021). In neighborhoods targeted by these policing strategies, rates of nonconsensual "stop-question-frisk" police contact with individuals engaging in *legal* behaviors have greatly increased (Justice, 2021). Policing experienced in ethnic-racial minority and low-income neighborhoods may be more invasive and harmful than that in white middle-class neighborhoods (Shedd, 2015). For example, minors and young men of color are more likely to be subjected to stop, question, and frisk encounters (Fagan, 2017; Rudovsky and Harris, 2018). Although no work has examined whether these policing practices directly impact self-regulation in early childhood, one longitudinal study of adolescent girls demonstrated that self-control and responsibility declined following police contact (Hipwell et al., 2018). Furthermore, prior work has shown that involuntary police contact and the threat thereof is associated with psychological distress and academic achievement (Gottlieb and Wilson, 2019; Justice, 2021), suggesting a link to self-regulation through stress physiology that may be particularly strong for children of color, especially Black boys. Directly experiencing police stops has been related to greater psychological distress among adolescents, which in turn predicts lower academic grades (Del Toro et al., 2022). These associations were similar across racial ethnic groups, but rates of being stopped were higher among Black youth and boys. Vicarious police stops (e.g., knowing someone who has been stopped by the police or witnessing someone stopped by the police in the neighborhood or at school) also contribute to poorer health for Black and Latinx youth (but not for white youth) as well as lower academic outcomes for Black boys (Legewie and Fagan, 2019; Del Toro et al., 2022) and for Latinx adolescents (Del Toro et al., 2022). Black youth, however, have been shown to experience greater psychological distress than both white and Latinx youth following a vicarious stop, which in turn predicted poorer grades (Del Toro et al., 2022). Additionally, Black boys have been shown to be particularly impacted by the threat of police contact such that test scores declined because of surges in police surveillance in the neighborhood (Legewie and Fagan, 2019). Furthermore, adolescents with lower levels of self-control are more likely to be stopped by police and also experience greater intrusiveness from police and higher emotional distress during encounters (Jackson et al., 2020). Because of this greater experience of distress, these adolescents may then be at higher risk for even greater declines in self-regulatory skills.

Immigration raids

There has been an increased presence of Immigration and Customs Enforcement (ICE) agents in the U.S. interior since the creation of ICE as part of the Homeland Security Act (American Immigration Council, 2017). ICE activity is associated with greater reports of stress and lower self-rated health scores among adults in impacted communities (Williams et al., 2017). Children are also affected by ICE activity in their neighborhoods (Dreby, 2012; Lopez, 2019). Analyses of 115 drawings by children enduring anti-immigrant policies in Maricopa County, Phoenix, Arizona document young children's preoccupations with the threat of family separation and the presence of ICE in their communities (Rodriguez Vega, 2018). This constant threat of familial separation and chronic uncertainty is theorized to have direct impacts on children both through deprivation and threat pathways (Barajas-Gonzalez et al., 2018, 2021). Although no studies have yet investigated direct impacts of immigration raids or ICE presence on child self-regulation, recent work has shown that immigration enforcement threat more generally is related to self-regulation in children in Pre-K (according to parent report), although it was unexpectedly related to higher ratings of self-regulation by independent observers (Barajas-Gonzalez et al., 2022b). This work suggests that neighborhood level factors such as ICE presence and raids—which likely increase immigration enforcement threat for children and families—may have impacts on children's self-regulation skills.

Built environment and self-regulation

Environmental pollutants

Exposure to environmental pollution comes from a number of sources which impact neighborhood air and water quality. Traffic related sources, including living near a major roadway or in an area of high traffic density, are a major cause of air pollution. Within urban areas, neighborhoods with higher percentages of families of color and families with lower socioeconomic status have greater exposure to air pollution (Hajat et al., 2013; Jones et al., 2014). Exposure to traffic related air pollution may lead to brain damage through neuroinflammation and oxidative stress pathways, or through neurotoxicity (Block et al., 2012). Areas of prefrontal cortex that support self-regulation may be particularly impacted by these neurobiological mechanisms (Calderón-Garcidueñas et al., 2008; Peterson et al., 2015), and air pollution has been shown to have direct effects on self-regulatory skills in childhood (Perera et al., 2012; Chiu et al., 2013; Sunyer et al., 2015; Harris et al., 2016). Living in high traffic density areas has been associated with teacher rated executive function skills in mid childhood (Harris et al., 2016). Exposure to traffic related air pollution has been associated with poorer inhibitory control (Chiu et al., 2013), slower growth in attention and working memory over a 12 month period (Sunyer et al., 2015), and higher attention problems (Perera et al., 2012).

Less work has examined pollution in drinking water which can be a conduit of other environmental exposures such as lead. Lead exposure in water is tied to neighborhood residence not only because of the age of housing stock and pipes, but also because of neighborhood struggles with financial resources, water sources, and aging infrastructure used for water distribution, as exemplified in the recent crisis in Flint, Michigan (Hanna-Attisha et al., 2016). Lead exposure has been associated with lower self-regulated attention among 4 and 5 year old children living in poverty (Davis et al., 2004).

Noise

High traffic density and having a major roadway nearby also create noise. Road traffic noise has been shown to increase stress (Babisch, 2011) and thus may have direct impacts on self-regulation by leading to repeated activation of, and thus alteration in, children's physiological stress systems. Studies investigating relations of noise to self-regulation have found that traffic noise at school impacts attention measured by both neuropsychological tests (Van Kempen et al., 2010) and teacher observations (Forns et al., 2016). Furthermore, higher levels of road traffic noise has been linked to greater parent reported inattention among 8-year-old children (Weyde et al., 2017).

Food environment

Neighborhoods where low-income, minority, or immigrant families live have been shown to lack supermarkets, grocery stores, and farmers' markets, resulting in lower availability of fresh, healthy, affordable foods (Mikkelsen and Chehimi, 2007).

Low-income families also have to travel further than higher-income families in order to reach supermarkets (Mikkelsen and Chehimi, 2007). Some evidence suggests that fast-food restaurants may be more prevalent in low-income neighborhoods, but other work suggests comparable accessibility across high and low-income neighborhoods (see Mikkelsen and Chehimi, 2007 for a review). Even in the case of comparable accessibility, however, fast food may be more salient in low-income neighborhoods because of the scarcity of healthy alternatives (Mikkelsen and Chehimi, 2007). Access to and affordability of healthy foods as well as availability of unhealthy foods are dimensions of the neighborhood food environment that may play a role in the development of self-regulation through pathways related to child nutrition (detailed in the Mediating Pathways section below). Access to healthy foods such as fruits and vegetables provides nutrients that support children's physical health and development (Morland et al., 2006; Powell et al., 2007; Bryant et al., 2020). One study to date has examined the direct link between the food environment and executive function among preschoolers (Bryant et al., 2020). Parent report of the food environment (access to, availability, and affordability of healthy food) was related to children's executive function. Food environment measured at the census tract level (i.e., a dichotomous indicator of access to supermarkets, supercenters, and large grocery stores), however, was not related.

Greenspace

Exposure to natural features, such as water, grass, and trees varies greatly across urban environments and tends to be more limited in disinvested areas. There are three potential pathways through which green space may impact children's self-regulation (Weeland et al., 2019). Access to greenspace may promote self-regulation by allowing children to experience more daylight and physical activity through playing outside (Beute and de Kort, 2014; Christian et al., 2015; Piepmeier et al., 2015). Natural greenspaces can also buffer against exposure to aspects of the built environment such as noise and pollution (Markevych et al., 2017; Weeland et al., 2019), and tree canopies have specifically been shown to be important for reducing traffic related air pollution and noise (Klingberg et al., 2017). Additionally, exposure to natural environments may replenish depleted self-regulatory resources (Kaplan and Berman, 2010) and restore affective and physiological processes that have been negatively impacted by stress (Ulrich, 1981, 1983; Ulrich et al., 1991). Two recent meta-analyses of the effect of exposure to nature among school-age children found benefits of nature for self-regulation across both correlational and quasi-experimental studies (Weeland et al., 2019). A few studies have specifically focused on the ways neighborhood greenspace relates to aspects of emotion regulation and executive function. In one study, the naturalness of the view from children's homes was related to attention and inhibition for girls, but not for boys (Taylor et al., 2002). Green space around children's homes longitudinally predicted self-regulatory problems reported by parents (Flouri et al., 2014). Higher lifelong residential neighborhood greenness longitudinally predicted better attention at 4–5 years of age and at 7 years of age (Dadvand et al., 2017). Greenness surrounding children's neighborhood, including home, commute, and school was associated with greater increases in working memory and declines in inattentiveness over a 12-month period among school-aged children (Dadvand et al., 2015).

Physical disorder

Physical disorder includes evidence of deterioration in the neighborhood, such as graffiti, litter, abandoned cars, broken windows, abandoned, vandalized or run-down buildings, and vacant housing (Sampson and Raudenbush, 1999). Aspects of physical disorder are visually prominent cues which can indicate crime in the neighborhood (Sampson and Raudenbush, 1999) and make residents feel fearful (Garvin et al., 2013). Additionally, disorder may indicate low collective efficacy for improving neighborhood conditions (Sampson and Raudenbush, 1999) in part because fear and related social isolation can impede collective efficacy, which perpetuates further disorder (Garvin et al., 2013). Furthermore, individuals living in areas with physical disorder indicate feeling negative emotions such as sadness, depression, and anxiety as well as feelings of being neglected, and physical disorder has been linked to mental health burden (Garvin et al., 2013). Consistent with these feelings of fear and negative emotionality, theoretical perspectives suggest that physical disorder promotes chronic stress and changes in physiological stress responses (Hill et al., 2005; Garvin et al., 2013). To our knowledge, studies have not yet examined the link between physical disorder and children's self-regulation, but we hypothesize that it may affect children directly as it does adults or indirectly *via* the home environment (described in the mediation pathways section below).

Education related resources

Education related resources, such as day care centers, schools, museums, libraries, community centers, and higher education institutions greatly influence children's opportunities for learning, and the presence and quality of these resources varies across neighborhoods even when they are similar in terms of socioeconomic characteristics (Wei W.S. et al., 2021). Access to high quality learning environments may support interactions with caregivers and teachers that could promote child self-regulation development (Rimm-Kaufman et al., 2009; Ursache et al., 2012; Wei W.S. et al., 2021). For example, higher quality child care has been shown to predict better executive function skills (Berry et al., 2014). Furthermore, access to education resources such as libraries and museums may scaffold parents in book sharing and play, which can improve the parent–child relationship (Weisleder et al., 2019) and thus self-regulation (as described in the section on home environment and resources pathway). Not having access to these resources may be a form of deprivation (i.e., limited cognitive and social stimulation), which is theorized to have direct consequences for executive function development (Sheridan and McLaughlin, 2016; Sheridan et al., 2017). Few studies have directly examined neighborhood education related resources in relation to self-regulation development in early childhood. One study investigated the relation of neighborhood resources more broadly to children's gains in executive functioning over the pre-K year, but did not find any evidence of associations (Wei W.S. et al., 2021).

Mediating pathways from neighborhood to self-regulation

In examining how neighborhood context influences self-regulation, we propose three mediating pathways across multiple ecological levels: (1) classroom environment and resources, (2) home environment and resources, and (3) child health behaviors. Although few studies have explicitly tested these mediating pathways, prior work links each of these potential mediators to both neighborhood context and to children's self-regulation. The studies reviewed below are not a comprehensive representation of this work but rather salient examples that suggest support for these pathways. Furthermore, the review emphasizes the emerging evidence linking neighborhood environment to the mediators given robust literatures that have established links from the mediators to self-regulation. In line with the bioecological model of human development (Bronfenbrenner and Morris, 2006; Center for Child and Family Well-Being, 2021), child health behaviors are nested within home environment and resources, which are nested within classroom environment and resources. Although beyond the scope of this review, empirical work has supported the theory that these levels reciprocally influence each other – context shapes child behavior, and child behavior shapes home and school contexts (Goldstein et al., 2001; Meltzer and Mindell, 2007; Aizer, 2008; Bell and Belsky, 2008; Pettit and Arsiwalla, 2008; Huang et al., 2013; Paschall and Mastergeorge, 2016; Brusseau and Burns, 2018; McKinnon and Blair, 2019; Pakarinen et al., 2021).

Classroom environment and resources

Neighborhood disinvestment is associated with characteristics of classrooms that provide early childhood care and learning opportunities. Broadly, disinvested neighborhoods tend to have public schools that are characterized by low resources, lower graduation rates, lower teacher certifications, and dilapidated facilities (Rothstein, 2013; Lynch, 2017; Pruitt et al., 2019). Neighborhood structural disadvantage has also been associated with lower quality of community child care programs (Phillips et al., 1994; Fuller et al., 1997; Loeb et al., 2004; Burchinal et al., 2008) although public investment in high quality early education may mean that there is a somewhat higher prevalence of high quality programs in some of the most disadvantaged neighborhoods (Phillips et al., 1994; Fuller et al., 2003). Neighborhood collective efficacy, however, may theoretically promote high quality classrooms by helping teachers to manage their own stressors as evidence demonstrates a link between neighborhood social resources and social support among residents (Mair et al., 2021). Early childhood classrooms can in turn support children's self-regulatory skills both through providing activities that explicitly teach emotion regulation and executive function skills as well as through creating safe, nurturing, and predictable environments that allow children to experience a level of physiological stress arousal that is conducive to using and developing emotion regulation and executive function skills (Ursache et al., 2012; Raver, 2014). Although there is nuance across studies, there evidence that higher quality classrooms are associated with higher self-regulatory skills for children from toddlerhood through kindergarten (Rimm-Kaufman et al., 2009; Weiland et al., 2013; Salminen et al., 2021). To date, only one study has directly examined classroom environment and resources as mediators of the link between neighborhood characteristics and children's self-regulation skills. This study found that lower neighborhood socioeconomic status was associated with lower classroom instructional quality which in turn was associated with smaller increases in children's executive function skills over the pre-K year (Wei W.S. et al., 2021). Relatedly, the link between neighborhood poverty and children's social–emotional skills more generally has been shown to be mediated by emotional support in the classroom (McCoy et al., 2015a), suggesting a similar pathway for classroom emotional support and self-regulation specifically.

Home environment and resources

Two models describe the home environment and resources as a link between neighborhoods and child outcomes: the family stress model (McLoyd, 1990; Conger et al., 1992) and the family investment model (Shuey and Leventhal, 2017). In line with the family stress model, parents' exposure to neighborhood stressors affects their own well-being and their parenting behaviors in ways that relate to children's development (Garner et al., 2021). Multiple aspects of neighborhood disadvantage can directly increase the stress that parents navigate on a daily basis, inevitably affecting their ability to provide the emotionally supportive, safe, nurturing, cognitively stimulating, and predictable home environments that are necessary to support self-regulation development (Brown and Ackerman, 2011; McCoy, 2013; Minh et al., 2017). For example, neighborhood violence has been shown to make parents less available for physical and emotional caretaking (Margolin, 1998; Farver et al., 2005). Greater neighborhood disorder is also associated with greater family conflict and harsher parenting (Barajas-Gonzalez and Brooks-Gunn, 2014). Neighborhood factors, however, can also help to buffer parents from these stressors. For example, collective efficacy is associated with greater social support among residents which likely promotes parent well-being and quality of parenting both directly and through buffering parents from stressful experiences (Armstrong et al., 2005; Mair et al., 2021). Similarly, neighborhood social cohesion has been shown to buffer the impact of financial deprivation on adult psychological distress such that among adults experiencing financial deprivation, those whose neighborhoods had high social cohesion experienced less psychological distress than those whose neighborhoods had low social cohesion (Erdem et al., 2016).

The family investment model suggests that neighborhood affluence increases parents' access to resources that support children's cognitive development and can reinforce effective parenting behaviors (Shuey and Leventhal, 2017). For example, neighborhoods that offer access to resources such as museums and libraries likely support parents to engage with their children in cognitively stimulating ways. More recently, there has been increasing recognition that these pathways are intertwined as they relate to child development (Weisleder et al., 2019; Garner et al., 2021). The relational health framework encompasses both of these perspectives by focusing on how safe, cognitively stimulating, emotionally responsive, and stable relationships can buffer children's adverse experiences and promote healthy development (Garner et al., 2021). Importantly, neighborhoods that are safe, stable, and nurturing communities include access to resources and services that promote the development of early relational health for families and their children (Garner et al., 2021). In turn these aspects of early relational health—emotionally responsive parenting behaviors and engagement in cognitively stimulating parent–child activities—have been shown to buffer child stress and support the development of self-regulation (Blair et al., 2014; Thompson, 2015; Weisleder et al., 2019; Hyde et al., 2022; Piccolo et al., 2022).

Child health behaviors

Third, the built and social environments that characterize children's neighborhoods influence children's health behaviors, including sleep, physical activity, and nutrition. Sleep, physical activity, and nutrition in turn play a role in setting the stage for the development of self-regulation skills (Becker et al., 2014; Williams et al., 2017; Breitenstein et al., 2021; Jackson et al., 2021).

Sleep

Neighborhood noise, environmental pollutants, access to physical activity amenities, population density, violence, and safety concerns have been shown to increase risk for poor sleep health and sleep disorders among children (Meldrum and Restivo, 2014; Lawrence et al., 2018; Hale et al., 2019; Koinis-Mitchell et al., 2019; Philbrook et al., 2020). Both theoretical and empirical research demonstrate that multiple aspects of sleep play an important role in children's development of multiple aspects of self-regulation (Williams et al., 2017; Breitenstein et al., 2021). A conceptual framework proposed by Breitenstein and colleagues suggests that in early childhood, sleep is reciprocally related to both physiological stress systems and to functioning of the prefrontal cortex and anterior cingulate cortex, brain areas that support self-regulation (Breitenstein et al., 2021). Consistent with this theory, sleep behavior, which undergoes rapid development in early childhood (Acebo et al., 2005), has been shown to longitudinally predict emotional and attentional aspects of self-regulation (Williams et al., 2017). Furthermore, sleep duration is consistently related to executive function both cross-sectionally and longitudinally (see Breitenstein et al., 2021 for a review).

Physical activity

Neighborhood housing density, walkability, traffic speed/volume, vegetation (ie., presence of street trees), access to recreation facilities, land use mix, and disorder, are all consistent predictors of physical activity among children (Roemmich et al., 2006; Miles, 2008; Ding et al., 2011). The role of park access in promoting physical activity is less consistent with some evidence suggesting null or inverse associations (Ding et al., 2011; McGrath et al., 2015). These unexpected findings may be explained by work demonstrating that physical disorder and perceived safety play an important role in whether adults encourage children to use local playgrounds (Miles, 2008). Work on the role of crime and safety, however, has been limited and more high quality work is needed to investigate this association (Ding et al., 2011), especially because for Black families, perceived neighborhood crime may be a particularly important factor in children's sedentary behavior (Budd et al., 2015). Research with both animals and humans, has shown that physical activity enhances aspects of self-regulation such as inhibitory control and executive function (Becker et al., 2014). For example, among pre-kindergarten children, greater time spent in active play during recess was related to greater self-regulation (Becker et al., 2014) and engaging in at least 60 min of physical activity 7 days a week was associated with self-regulation in middle childhood (López-Gil et al., 2020). Furthermore, experimental work which implemented an exercise intervention with overweight 7–11 year old children improved executive function and increased activity in the prefrontal cortex, an area of the brain important for self-regulation (Davis et al., 2011).

Nutrition

The relation between neighborhood access to healthy foods and individual consumption of fruits and vegetables has mainly been studied in adults, but this pathway likely extends to children (Mikkelsen and Chehimi, 2007). Furthermore, Latinx mothers have described how pervasive access to fast food restaurants and intensive marketing to children have led their children to consume more unhealthy foods (Jones, 2002). Nutrients from healthy foods such as fruits and vegetables are necessary to support brain development underlying cognition, and nutritional deficiencies may have greater impacts on cognition in times of rapid brain development such as in early childhood (Morland et al., 2006; Powell et al., 2007; Nyaradi et al., 2013; Wachs et al., 2014; UDHHS, 2015; Bryant et al., 2020). Consistent with this pathway, food insecurity—low or uncertain access to affordable nutritious foods—has been associated with increased risk for self-regulation difficulties in early childhood (Jackson et al., 2021).

Thus, theory and empirical research support three multilevel mediation pathways linking neighborhood context to children's self-regulation through (1) classroom environment and resources,

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(2) home environment and resources, and (3) child health behaviors. Future work is needed to explicitly test these mediation pathways individually and in parallel.

Cultural strengths

Families of color have particular cultural strengths that are often absent from discussion about disinvested neighborhoods. For example, some of the cultural assets of Black American families include optimism, extended kin and social networks, and religiosity and spirituality (Harrell, 2022; Lloyd et al., 2022). Similarly, some of the cultural assets of Latinx families include religiosity and spirituality, a collective orientation, and familism, which emphasizes solidarity, loyalty and reciprocity among family members (Zambrana and Zoppi, 2002; Calzada et al., 2013). Theoretically, these cultural assets can help buffer the impact of neighborhood risk factors on child outcomes by shaping processes at multiple levels and at multiple points in the pathway from neighborhood to self-regulation. We explore collective efficacy and home environment as two examples of pathways through which cultural assets may support self-regulation in the face of neighborhood disadvantage. We focus on Black and Latinx families who are better represented in the literature to date, but emerging work is also investigating these relations in Asian American families (Wei W. et al., 2021).

Cultural assets may scaffold the development of collective efficacy. For example, one study showed that higher concentrations of African American and residentially stable residents in one's neighborhood was associated with greater cumulative social support and perceptions of neighborhood cohesion which in turn was linked to fewer internalizing symptoms among adolescents (Hurd et al., 2013). Furthermore, Black churches, which are a central institution in urban Black neighborhoods, can support collective efficacy by coordinating residents and organizations to address youth violence (Pegram et al., 2016).

Additionally, cultural strengths may buffer the link between neighborhood risk factors and children's self-regulation through processes in the home environment. For example, in a cross-sectional study of Mexican American youth, higher levels of familism behaviors were protective for youth resilience at both low and high levels of neighborhood hazards (i.e., crime, gangs, traffic, and noise; Romero et al., 2020). Similarly, the association between perceptions of neighborhood danger and harsh parenting has been shown to be moderated by cultural values among Mexican American families (Gonzales et al., 2011; White and Roosa, 2012). Furthermore, cultural strengths can support racial-ethnic socialization (Rivas-Drake and Witherspoon, 2013; Brittian Loyd and Williams, 2017; Anderson and Stevenson, 2019). Research with adolescents suggests that racial-ethnic socialization has potential to buffer impacts of stressful discriminatory experiences on self-regulation (Rivas-Drake et al., 2014; Umaña-Taylor and Rivas-Drake, 2021), but whether these findings generalize to neighborhood level stressors or to young children has not yet been explored.

Evidence from interventions in high risk neighborhoods

The conceptual model elucidates multiple points for intervention to address neighborhood impacts on child self-regulation. First, we highlight promising approaches that directly change the built or social environment. Next, we summarize key findings from prevention science, which has focused primarily on mitigating the impact of poverty through classroom and home-level interventions. Taken together, experimental evidence strengthens confidence in the causal nature of the links in Figure 1, supports the value of interventions to protect children from neighborhood risk, and underscores the need for structural solutions to structural problems (Brown et al., 2019).

Neighborhood-level intervention and policy change

With increasing understanding of structural racism, there is increasing commitment to addressing the problem directly by re-investing in neighborhoods. Bailey et al. (2017) describe how *place-based, multisector, equity initiatives* can work. Federal initiatives launched in the past decade (Promise Neighborhoods and Choice Neighborhoods) are based largely on the success of Purpose Built Communities (2015) and their original 1995 redevelopment initiative in Atlanta, GA. In addition to $123 million (compared to no capital investment in the 30 years prior), this partnership between the Atlanta Housing Authority, leaders from the community and public housing, and philanthropy resulted in high-quality, mixed-income housing; cradle-to-college education, and a series of programs chosen by residents – with dramatic changes in employment and crime within 10 years (Bailey et al., 2017).

Specific *improvements to the built environment* in disinvested neighborhoods have also been evaluated. A review of experimental and quasi-experimental studies indicates that housing and blight remediation of buildings and land is practical, sustainable, and shows consistent reductions in violent crime (Kondo et al., 2018). For example, a citywide cluster randomized trial in Philadelphia found that "cleaning and greening" vacant lots significantly reduced crime and gun violence in particular; further, based on reports from residents near greened lots, this low-cost remediation increased use of outdoor spaces for relaxing and socializing and reduced fear (Branas et al., 2018), feelings of worthlessness, and depression (South et al., 2018).

Participatory budgeting is a "democratic process in which community members decide how to spend part of a public budget." Originating as an anti-poverty policy in Brazil, it is now used broadly to allocate state and local budgets with important neighborhood impacts. Municipal governments with participatory budgeting (120 of Brazil's largest cities) allocated more funds to sanitation and health services than other municipalities (adjusting for economic and political differences). Strikingly, in cities with sustained political commitment for participatory budgeting for >8 years, records revealed a nearly 20% drop in infant mortality (Gonçalves, 2014; Touchton and Wampler, 2014).

Public investment in high quality early care and education is seen as a powerful policy lever to address inequities rooted in structural racism (Heckman et al., 2013). Nearly all states are building the infrastructure to provide high-quality preschool, reaching 30% of 4-year-old across the country (Phillips et al., 2017). Increased access to educational opportunities lays the foundation for classroom environments which may buffer neighborhood risk. For example, Boston's pre-K program (with evidence-based curricula, bachelors/masters-level teachers, and coaching) improved executive functioning and emotional development (as well as literacy and math; Weiland and Yoshikawa, 2013). Ongoing research evaluates impacts at scale (Phillips et al., 2017) and scholars advocate for elevating the status of the early education workforce, which is majority women of color, often not earning a living wage (U.S. Department of Education, 2016; Washington, 2017).

Classroom and home-level intervention

Robust evidence documents the central role of classroom and home environments in promoting child self-regulation within high risk contexts. Key findings from this literature align with our conceptualization: (1) there is substantial variability in children's emerging self-regulation within historically disinvested neighborhoods; (2) home and classroom environments are malleable; and (3) bolstering adult capacity to provide emotionally responsive, cognitively stimulating environments despite the broader context confers meaningful benefits for child self-regulation (e.g., Head Start REDI; Bierman et al., 2008; Chicago School Readiness Project; Raver et al., 2009; Family Check-up in WIC clinics; Chang et al., 2014; Video Interaction Project in primary care; Weisleder et al., 2016; Canfield et al., 2020). For example, in Head Start centers in historically disinvested neighborhoods in Chicago, improvements in teacher-child relationships explained improvements in self-regulation (which explained academic outcomes Raver et al., 2011; Jones et al., 2013). Long-term follow-up considered the ongoing influence of crime (average > 600 incidents/year); though modest, intervention impact on social–emotional trajectories was actually stronger for children who attended elementary schools in census tracts with higher levels of crime (McCoy et al., 2018).

ParentCorps is a family-centered enhancement to pre-Kindergarten in historically disinvested neighborhoods and includes home and classroom components, as well as a child component which directly supports healthy eating, activity, and emotion regulation (Dawson-McClure et al., 2022). Trials in New York City schools demonstrate that ParentCorps is working as intended, and that changes in children's proximal environments during this critical developmental period lead to sustained improvements across three domains: academic achievement, physical and mental health (Brotman et al., 2011, 2012, 2013, 2016; Dawson-McClure et al., 2015). While ParentCorps was not designed to address neighborhood-level factors, fundamental to this approach is building relationships with and a sense of community among parents – an enduring "corps" of support (Brotman et al., 2011). Facilitators explicitly affirm parents' inherent value, actively support their autonomy, and honor culture as important and adaptive (Garcia-Coll et al., 1996). In this context of being seen, heard, and cared for – parents share about their lived racial experiences, reflect on sources of support in their community, and consider changes in alignment with their values and beliefs (Dawson-McClure et al., 2022).

Limitations

Despite the many innovative aspects of this model conceptualizing the development of early childhood self-regulation in neighborhood context, some important limitations remain. First, the model focuses on self-regulation in early childhood. Extending this model to adolescence, a second period of heightened developmental plasticity in brain areas important for self-regulation, is important and will necessitate consideration of the increasing ways in which older children engage with their neighborhood contexts. Different mediational processes, for example, through experiences with peers and through racial-ethnic socialization also warrant consideration. Second, a life-span model will also need to consider how the impact of neighborhood factors may change with child age and consider issues of timing between neighborhood exposures and self-regulatory outcomes. Relatedly, this model does not consider genetic levels of influence or the ways in which intergenerational transmission of self-regulation may occur in the context of historical disinvestment. Third, individual-level factors that may moderate relations between neighborhood context and self-regulation are not a focus of this model. For example, individual-level factors may preclude a family from accessing neighborhood resources because of legal restrictions or because they may not feel safe or welcome doing so (Barajas-Gonzalez et al., 2022a). Finally, the model situates the development of self-regulation within structural racism, but does not discuss the ways in which *interpersonal* racism and discrimination may affect self-regulation. Recent work demonstrates that racism is a ubiquitous experience for children of color across many different types of neighborhoods (Zimmerman et al., 2022), and future work is needed to conceptualize and examine the ways in which interpersonal racism and discrimination impact self-regulation in these contexts.

Conclusion

Our conceptual model of self-regulation in the context of historically disinvested neighborhoods advances understanding of the ways in which built and social environments shape the development of self-regulation in early childhood. In centering children of color growing up in historically disinvested neighborhoods, this model takes as its starting point the ways in which structures of racism and social stratification have shaped the built and social environment. Furthermore, we advance a multilevel approach which examines classroom environment and resources, home environment and resources, and child health as three potential pathways linking neighborhood contexts to self-regulation. Finally, racial-ethnic cultural strengths and multilevel interventions have the potential to buffer children's development of self-regulation in disinvested neighborhood contexts. Advancing multilevel approaches to understand the development of self-regulation among children of color living in historically disinvested neighborhoods is an important step in efforts to promote equity in health and education.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Brett Miller,
National Institutes of Health,
United States

REVIEWED BY
Callie Little,
University of New England, Australia
Anna Johnson,
Georgetown University,
United States

*CORRESPONDENCE
Teka Lenahan
tl3trk@virginia.edu

†These authors have contributed equally to this work

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Examining the association between neighborhood conditions and school readiness across low and highly segregated school attendance boundaries

Teka Lenahan[1*], Jennifer LoCasale-Crouch[1†], Caroline Chamberlain[1†], Amanda Williford[1], Jason Downer[1], Jessica Whittaker[1] and Luke Miller[2]

[1]School of Education and Human Development, Center for Advanced Study of Teaching and Learning, University of Virginia, Charlottesville, VA, United States, [2]School of Education and Human Development, EdPolicyWorks, University of Virginia, Charlottesville, VA, United States

Neighborhood characteristics are well documented determinants of adolescent and adult health and well-being. One such neighborhood characteristic heavily explored in K-12 research is the role of residential segregation on educational outcomes. Surprisingly, little is known about how community conditions, as well as racial segregation, relate to children's early school readiness. This is a critical gap in the field as children's school readiness is a significant marker of school success, both in the short and long term. Thus, this study aimed to address this gap through examining statewide school readiness data and neighborhood opportunity resources related to early childhood development. Student-level readiness data from 84,720 kindergarteners collected through the 2019 Virginia Kindergarten Readiness Program were used to determine whether a student demonstrated school readiness skills. Community conditions surrounding a school were constructed using geospatial mapping of the 2015 School Attendance Boundary (SAB) Survey and Child Opportunity Index 2.0. This study then explored the role of neighborhood segregation in a SAB with student's school readiness with three separate approaches (entropy, exposure, and share of racial/ethnic groups). A series of logit regression models were used to examine the relationship between community resources and the likelihood a student was school-ready and whether this relationship varied across low and highly segregated SABs. Results indicated that a student in a higher resourced community was more likely to be school ready than a similar student in a lower resourced community. Distribution of students by race/ethnicity across neighborhood resource levels was uneven. Specifically, Black and Hispanic children are overrepresented in lower resourced communities, and White and Asian children overrepresented in higher resourced ones. Further, in two out of three measures of segregation, results show significant variation between neighborhood resources and school readiness likelihood across different levels of segregation. Consistently, students within a more segregated (and particularly Segregated Black or Hispanic) SAB were more sensitive to changes in community resources than those in less segregated SAB. Program and policy implications are discussed.

KEYWORDS

school readiness, early childhood, geospatial analyses, Virginia, neighborhood conditions, education, race, segregation

Introduction

The neighborhoods in which children grow up are linked with a host of short- and long-term outcomes, ranging from physical and mental health (Ross, 2000; Ross and Mirowsky, 2001; Kim, 2010) to earnings (Galster et al., 2007; Chetty et al., 2016) to school achievement and attainment (Dupéré et al., 2010; McCoy et al., 2015). However, relatively little is known about how neighborhood conditions, including neighborhood opportunity and racial segregation, contribute to or potentially remedy developmental inequities at the critical time before children enter school (Rimm-Kaufman et al., 2000; Minh et al., 2017). A recurrent challenge is the lack of generalizable neighborhood-level measures that provide a comprehensive picture of the myriad of factors that are important for young children's healthy development. The Child Opportunity Index (COI), a census tract-level index composed of neighborhood features associated with children's development, offers a potential solution to measure neighborhood opportunity. Emerging research suggests that the COI may be a useful tool to understand inequities in early childhood (Hardy et al., 2021), but the relationship between the COI and children's school readiness skills has not yet been explored. In addition, it is important to consider the role of the COI's developmentally-salient neighborhood resources in the context of racial segregation, which reflects another structural feature of communities with established links to child and adolescent school achievement and attainment (Wells and Crain, 1994; Sampson et al., 2008; Reardon, 2016). Little is known about how neighborhood segregation may affect children prior to school entry, despite evidence that young children experience racial segregation in preschool (Frankenberg, 2016). This study, then, aims to address this gap by examining the extent to which neighborhood opportunity is associated with a child's school readiness skills and how this association varies by community racial segregation levels.

Children's early school readiness skills are a key predictor of future development

The early childhood years are a critical developmental period, as children begin to experience the world and learn from families, teachers, and peers. It is during these years, from birth through kindergarten, that children learn and acquire skills that lay the foundation for the rest of their education (Shonkoff and Phillips, 2000; Annie E. Casey Foundation, 2013). These skills encompass various domains of child development and learning, such as cognitive skills (including literacy, language, math, and science skills, as well as approaches to learning), social–emotional skills (including self-regulation, interpersonal skills, and behavior), and other aspects of health and physical well-being (including fine and gross motor skills and physical fitness; Annie E. Casey Foundation, 2013; Latham, 2018). Importantly, these school readiness skills are linked to various academic, social, and adult outcomes (Hamre and Pianta, 2001; Heckman, 2006; Duncan et al., 2007; Galster et al., 2007; Chetty et al., 2011).

A wide body of research indicates that there are significant gaps in children's school readiness skills across racial/ethnic lines (Isaacs, 2012; Reardon and Portilla, 2016; Latham, 2018), and these gaps emerge due to learning opportunity disparities during early childhood (Rimm-Kaufman et al., 2000; Lee and Burkam, 2002; Magnuson et al., 2004; Pratt et al., 2016). Studies have also shown that racial gaps in school readiness exist, such that White children tend to score higher on various school readiness skills than Black and Hispanic children (Sonnenschein and Galindo, 2015; Reardon and Portilla, 2016; Latham, 2018). For instance, Latham (2018) found that Black children entered kindergarten half a grade behind White children in math, whereas Hispanic children entered two-thirds of a grade behind White students in math. Similarly, Black children were about one-fifth of a grade behind White children in literacy skills, and Hispanic children were about a third of a grade behind White children in literacy. While some research indicates school readiness gaps have narrowed over the past few decades, significant differences between student subgroups still exist (Reardon and Portilla, 2016; Latham, 2018).

When children enter school less ready for kindergarten, there are implications for kindergarten and later schooling. Children who start school less ready than their peers have to play catch up, and research indicates these gaps persist past kindergarten (Reardon and Portilla, 2016). The school readiness gaps can also lead to progressively bigger differences in children's educational outcomes, negatively affecting children much later in school and life (Belsky and MacKinnon, 1994; Hamre and Pianta, 2001; Sadowski, 2006; Duncan et al., 2007; Galindo and Sonnenschein, 2015). For example, in their meta-analysis of six longitudinal datasets, Duncan et al. (2007) found that math and literacy skills at the start of kindergarten were associated with learning outcomes later in elementary school. Similarly, Hamre and Pianta (2001) found an association between academic and behavioral outcomes through eighth grade for students with high levels of behavioral problems in kindergarten. Thus, if gaps are not addressed early, they can pose problems down the line.

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Development happens in the context of neighborhoods

Understanding how and why school readiness gaps exist between children is a complicated yet crucial topic. Researchers are beginning to think more ecologically to explain differences beyond child and family characteristics (Bronfenbrenner, 1976). Neighborhoods are a critical context to consider, as they play an essential part in children's development and education and are potential targets for policy prevention and intervention efforts. Neighborhood conditions (e.g., availability of early childhood programs, neighborhood poverty and employment rates, access to healthy foods) are robust predictors of child and adolescent outcomes, including higher prosocial behaviors, cognitive skills, and school achievement and attainment (Kohen et al., 2008; Dupéré et al., 2010; Odgers et al., 2012; McCoy et al., 2015; Minh et al., 2017; Leventhal, 2018). Similarly, an extensive body of research indicates neighborhoods affect children into their adulthood, as seen through impacts on earnings potential, socioeconomic mobility, marriage status, and life expectancy (Sharkey and Faber, 2014; Acevedo-Garcia et al., 2016, 2020; Chetty et al., 2016; Chetty and Hendren, 2018). Thus, the neighborhoods where children grow up impact not only their current day-to-day experiences but also their experiences in later childhood, adolescence, and adulthood.

Previous neighborhood research has predominantly focused on the influence of communities on adolescent and adult outcomes (Minh et al., 2017). While there has been some research examining these connections in early childhood, evidence suggests this is a path worth exploring (McCoy et al., 2015). For example, McCoy et al. (2015) found that neighborhood poverty directly predicted children's pre-academic outcomes in Head Start. Similarly, Vaden-Kiernan et al. (2010) found direct links between school neighborhood disadvantage and Head Start students' math and language skills. Importantly, neighborhood structural characteristics, such as housing conditions and socioeconomic advantage, have been shown to shape child outcomes even when controlling for characteristics of families and schools, suggesting that children's neighborhoods represent a distinct and salient component of their ecologies (Klebanov et al., 1997; Leventhal and Brooks-Gunn, 2004; Kohen et al., 2008; Dupéré et al., 2010; Coulton et al., 2016). Recent research has also found that neighborhoods can provide protective factors for low-income preschoolers. For example, high-resource neighborhoods were associated with gains in children's executive function skills (McCoy et al., 2022), especially in lower income but higher-resourced neighborhoods (Wei et al., 2021). These findings suggest that neighborhoods are a key context to explore in considering children's developing school readiness skills.

While most research exploring neighborhoods has used socioeconomic status (SES) of residents as the key distinguishing metric, recent research suggests that defining neighborhoods in this way falls short of capturing important variation in living conditions and resources (Wei et al., 2021). Thus, to better reflect the range of neighborhood conditions associated with children's development, Acevedo-Garcia et al. (2016, 2020) created the Child Opportunity Index (COI). The COI 2.0 is a census tract-level index, compiled across a range of publicly available data, and consists of 29 indicators measuring place-based resources such as access to and quality of early childhood education, access to healthy foods, and availability of green space, toxin-free environments, and socioeconomic resources (Diversitydatakids.org, 2022). The COI uses these various indicators and community resources to evaluate neighborhood opportunity. In addition to previous research linking the individual COI indicators to aspects of children's development, the overall COI composite measure has also been associated with life expectancy and intergenerational socioeconomic mobility (Acevedo-Garcia et al., 2020).

Research using the COI shows that neighborhood opportunity, or the community conditions that foster child development, varies considerably by race and ethnicity (Acevedo-Garcia et al., 2016, 2020; Hardy et al., 2021). For example, Hardy et al. (2021) found that nearly half of White children from low-income families live in moderate-, high- and very high-opportunity neighborhoods, whereas almost a quarter of White children from low-income households live in very low-opportunity neighborhoods. On the other hand, close to 70 percent of Black children from low-income families live in very low-opportunity neighborhoods. This means that Black children from low-income households are three times more likely than White children in similarly low-income households to live in neighborhoods with the lowest opportunity levels (Hardy et al., 2021). Thus, examining the relationship between the COI and children's school readiness, in the context of racial segregation, appears warranted.

Community segregation and children's development

Another important neighborhood condition, in addition to neighborhood opportunity is the racial segregation of neighborhoods and schools. After the *Brown v. Board of Education* ruling, school segregation began to decrease (Reardon and Owens, 2014; Fahle et al., 2020). Some research, however, indicates that school racial segregation has increased over the past few decades (Orfield et al., 2014; Ayscue and Orfield, 2015; Rothstein, 2015), especially once court-ordered integration policies came to an end (Liebowitz and Page, 2014). Further, housing policies, such as redlining, whereby banks denied loans and mortgages to Black families to prevent them from living in certain suburbs and neighborhoods, have added to ongoing neighborhood segregation (Rothstein, 2015). Despite the ending of the practice decades ago, research points to inequitable housing policies as leading to a wealth gap between White and Black families. This, along with continued gentrification of neighborhoods, has contributed to the ongoing segregation of families and schools (Rothstein, 2015; Pearman, 2019).

Residential segregation appears particularly salient for children's school achievement (Owens, 2017). For example, segregation was found to be a significant predictor of racial achievement gaps for math and English language arts assessments for students in grades three through eight (Reardon et al., 2019). Similarly, racial residential segregation was associated with lower rates of high school and college graduation for Black students (Quillian, 2014). Recent studies have also examined the relationship between racial segregation and school experiences. For example, Owens (2020) found that schools with larger populations of Black and Hispanic students tended to have harsher disciplinary measures, higher levels of chronic absenteeism, and less-experienced teachers. Additionally, a study of Chicago schools and neighborhoods found that segregation led to differences in school experiences, with Black students more likely to experience prison-like surveillance practices in their schools than White students (Shedd, 2015).

Segregation is not unique to school-aged children. A recent study found that preschools were more racially segregated than K-12 programs (Frankenberg, 2016). Specifically, Frankenberg (2016) discovered that over half of Black and Hispanic students attended public preschools, where children of color accounted for at least 90% of the student population. Further, White children were the most racially isolated ethnic group, relative to their own racial/ethnic group, with White students attending preschools that were 70% White on average (Frankenberg, 2016). However, how segregation affects young children and their emerging school readiness skills, particularly when considered alongside a robust measure of neighborhood resources like the COI, has not been studied. Further, it is unclear whether higher levels of segregation will amplify or mitigate any potential relationship between neighborhood opportunity and the development of school readiness skills when interacted with one another. Given that prior research has found positive associations for academic and social outcomes for children who experience diverse and integrated early childhood settings (Reid and Kagan, 2015; Wells et al., 2016; McArdle and Acevedo-Garcia, 2017), higher levels of segregation may diminish school readiness. Alternatively, for children of color, higher levels of segregation could have a positive impact on the relationship between neighborhood opportunity and children's school readiness skills. For instance, children of color in highly segregated areas may be more likely to have early childhood teachers and caregivers of their same race or from similar backgrounds (Paschall et al., 2020). Research has found that when early childhood educators and children are the same race, teachers are more likely to give students higher academic ratings (Downer et al., 2016; Redding, 2019) and may use fewer exclusionary discipline practices (Wymer et al., 2022). In this way, higher levels of segregation may have the potential to serve as a protective factor for children of color.

Important to note is that there are a variety of ways to operationalize segregation (Reardon and Owens, 2014). One way to measure segregation is to use Theil's entropy index, which looks at the relative distribution of racial groups in an area (Reardon and Firebaugh, 2002). In other words, the entropy index evaluates the distribution of race in one neighborhood relative to the distribution in other neighborhoods. The entropy measure is unique in that it measures segregation across multiple races, as opposed to more traditional methods of evaluating just two racial groups (Stroub and Richards, 2013). Another common measure of segregation is to evaluate the extent to which children of one racial group are exposed to children of other racial groups, called the exposure index (Stroub and Richards, 2013; Reardon and Owens, 2014; Frankenberg, 2016). For example, a neighborhood with a high proportion of children of color relative to White children would be considered a segregated neighborhood, as would a neighborhood with a high proportion of White children relative to other children of color. Finally, an additional method to measure segregation is to evaluate the share, or proportion, of different racial groups within a neighborhood (Stroub and Richards, 2013; Ayscue and Orfield, 2015). While the exposure measure analyzes the proportion of a racial group relative to another racial group, the share measure of segregation looks at the overall distribution of racial groups in a neighborhood.

Each of these three segregation measures provide unique contributions to conceptualizing children's neighborhood experiences. First, the exposure measure is an important contribution because it measures the probability that a child of one racial group may be exposed to a child of another racial group, thus capturing the potential interactions between different racial groups and allowing us to analyze the average or typical experience of a child from different racial groups (Frankenberg, 2016). Exposure is also unique because interaction probabilities are not symmetrical, meaning the probability that a White child may be exposed to a Black child is not necessarily the same probability that a Black child may be exposed to a White child (Forest, 2005). The share measure of segregation is also significant because it closely aligns with how people conceptualize segregation. Further, while the exposure measure evaluates probabilities, the share measure provides the actual racial composition of a neighborhood. Additionally, as entropy evaluates segregation across multiple racial groups, this allows for the measurement of "overall" segregation, as opposed to evaluating differences between racial groups. On the other hand, the exposure and share measures enable us to analyze both the influence of segregation and whether there was an association based on a racially dominant group in a segregated neighborhood. As all three of these segregation measures offer unique information about children's experiences in their neighborhoods, each of these were pursued in this study.

School attendance boundaries are a salient context for young children's development

As children age, schools become a central feature of their community, existing within neighborhoods defined by attendance boundary zones. While prior research has defined neighborhoods using census tracts (McCoy et al., 2015, 2022; Wei et al., 2021) or block groups (Dupéré et al., 2010), attendance boundaries provide a direct relationship between schools and the surrounding geographic area. School attendance boundary zones are drawn within school districts to determine which public school children attend based on where they live. For example, if there are three elementary schools in one school district, there will be boundary zones to delineate which neighborhoods will attend which elementary school. In some school districts, families may be able to choose which school their child goes to, but most attend their assigned schools. These boundary zones also only apply to public schools; families may choose to attend other school programs, such as private or charter schools (Bischoff and Tach, 2018), that are not subject to boundary zones.

Hypothetically, attendance boundary zones should be drawn in consideration of the number of students and schools (with even proportionality in mind), as well as the distance between neighborhoods and schools, but this is not always the case. A study in 2015 found that school attendance boundary zones were not “accidents of geography” but instead were shaped in irregular ways (i.e., gerrymandered), perhaps to alter the composition of schools (Richards and Stroub, 2015). Studies have examined the effects of gerrymandered attendance boundary zones, especially related to racial segregation of schools (Richards, 2014; Saporito and Van Riper, 2016; Monarrez, 2021), but findings are mixed. Some studies found that gerrymandered boundary zones were related to increased racial segregation (Richards, 2014; Monarrez, 2021). A separate study, however, found that some irregularly shaped, gerrymandered districts had more racial *integration* than expected (Saporito and Van Riper, 2016). Districts, thus, may purposefully draw irregularly shaped boundary zones to achieve racial school integration in diverse neighborhoods (Saporito and Van Riper, 2016) or to fulfill court-ordered desegregation directives (Richards, 2014).

Additionally, it is important to note that attendance boundary zones are not a fixed entity, due to the continuously changing nature of neighborhoods and local populations. Typically, these changes occur over time to accommodate population growth or decline depending on the neighborhood. Schools in rapidly expanding neighborhoods may become overcrowded, whereas schools in less populous neighborhoods may be able to take in more students. School districts may also build new schools to address population growth or to replace aging buildings. However, these changes also present opportunities to racially gerrymander attendance boundary zones. For example, various studies found gerrymandering particularly evident in school districts that experienced rapid diversification (Siegel-Hawley, 2013; Richards, 2014; Richards and Stroub, 2015). Thus, school attendance boundaries serve as one compelling approach to defining neighborhoods, when considering children’s community experiences of resources and segregation.

The current study

This study aimed to expand understanding of the intersection between children’s school readiness and two types of neighborhood conditions: neighborhood opportunity and residential racial segregation. Using statewide kindergarten readiness data, this study examined how neighborhoods, defined by school attendance boundaries, varied in the conditions that foster children’s development and whether this variation contributed to childrens’ school readiness skills. In particular, this study utilized a novel application of the Children’s Opportunity Index to represent neighborhood opportunity within school attendance boundaries and explores whether neighborhood racial segregation amplified or muted associations observed between neighborhood opportunity and children’s school readiness skills. The specific research questions were:

1. Is a child’s likelihood of being school ready associated with the neighborhood opportunity within their school attendance boundary?
2. Does the association between school readiness and neighborhood opportunity within a child’s school attendance boundary vary by residential racial segregation?

Findings will better equip state and local policymakers to understand neighborhood conditions in relation to school readiness, which in turn could be used to inform decision making about community investments to support children’s school readiness skills.

Materials and methods

Study context

This study leveraged student-level kindergarten readiness data collected through Virginia’s statewide readiness assessment system. The assessments included measures of literacy, mathematics, self-regulation, and social skills which, when combined, establish a comprehensive, consistent statewide baseline of children’s overall school readiness. The school readiness assessments were administered by teachers in both the fall and the spring. For this analysis, the Fall 2019 assessments were used for several reasons. First, these data represented the first-time assessments were completed statewide and included over 99% of the expected kindergarten population (Virginia Kindergarten Readiness Program, 2021). Second, the population reflects the Commonwealth’s racial (20.4% Black), ethnic (17.2% Hispanic), and socioeconomic (37.6% economically disadvantaged) diversity. Third, these assessments predate the Covid-19 pandemic. Finally, the fall assessment captures students’ school readiness skills as they enter kindergarten, minimizing skill variation attributed to kindergarten teacher and elementary school quality.

Student participants

In Fall 2019, 91,210 kindergartners across 1,106 schools completed the school readiness assessments (Virginia

Kindergarten Readiness Program, 2021). This study utilized school attendance boundaries as the geographic organizer for neighborhoods (details to follow). Attendance boundary information was missing for 68 schools, and another four schools were dropped as they had less than half of their expected students' skills assessed (Virginia Department of Education, 2019). In addition, student characteristics were missing for 998 students and assessments were missing for 467 students. Thus, the final analytic sample included 84,720 students across 1,034 schools, 92.9% and 93.5% of the original sample, respectively. Difference-in-means *t*-tests revealed that the sampled students were not significantly different from the broader sample on any demographic or outcome variable except for the proportion of White students. The sample contained 0.61 percentage points fewer White students (47.8% and 47.2%, $p = 0.0058$).

Measures

School readiness

Virginia's statewide assessment system includes assessments of students' skills across four domains: literacy, mathematics, self-regulation, and social skills. The Phonological Awareness Literacy Screening-K (PALS-K) assessed young children's knowledge of important fundamental literacy skills ranging from letter sounds and rhyme awareness to spelling and word recognition, which has shown adequate task and inter-rater reliability, as well as criterion-related validity, over time (Invernizzi et al., 2015). The Early Mathematics Assessment System (EMAS) measured children's mathematics knowledge and skills. EMAS is designed to measure children's skills across four areas: Geometry, Patterning, Numeracy, and Computation. Testing items were selected to represent a range of skills across the four subdomains and to target an appropriate level of difficulty. The EMAS has shown strong internal consistency ($\alpha = 0.905$) within the dataset (Ginsburg et al., 2010). Teachers' perceptions of students' self-regulation and social skills were assessed using the Child Behavior Rating Scale (CBRS; Bronson et al., 1990; Matthews et al., 2009). The CBRS is a teacher-report measure consisting of 17 items, 10 assessing self-regulation and seven assessing social skills, that measure teachers' perceptions of a student's behavioral regulation in both academic and social situations. After observing students' behaviors in the classroom, teachers completed the rating scale where each item asks them to rate the frequency with which a student exhibits a specific behavior from one (never) to five (always). The CBRS has shown strong reliability ($\alpha = 0.89$–0.95; Tindal et al., 2015; Moldovan and Bocos-Bintintan, 2016) as well as construct, concurrent, and predictive validity (Ponitz et al., 2009; Wanless et al., 2011; Gestsdottir et al., 2014; Schmitt et al., 2015).

Benchmarks for the mathematics (Early Mathematics Assessment System), self-regulation, and social skills (Child Behavior Rating Scale) assessments were established using developmental expectations in conjunction with data collected across the Commonwealth during the 2015–2019 pilot phase. Students scoring below these benchmarks are most likely not demonstrating the level of skills one would expect for a kindergarten student. The literacy assessment (PALS) uses benchmark scores to indicate whether a student has a heightened risk of long-term reading challenges (Phonological Awareness Literacy Screening, 2021). Students were considered overall "Ready" if they scored at or above the benchmark in all four readiness domains. Conversely, students were considered "Not Ready" if they scored below the benchmark in one or more of these four domains. This study uses this dichotomous overall readiness variable as the outcome in all models. While a binary outcome reduces the power of the analysis relative to a continuous outcome measure, this variable is consistent with the Virginia Department of Education's definition of school readiness (Altman and Royston, 2006). Using this dichotomous readiness variable allows for both a consistent measure to compare this study's results with previous research as well as a policy relevant definition useful for state and local policymakers. Overall readiness rates are shown below in Table 1.

School attendance boundary

School Attendance Boundaries (SAB), or school feeder zones, are the geographical area served by a school. The National Center for Education Statistics' (NCES) School Attendance Boundary Survey is one of the most complete and up-to-date sources of SABs available. Conducted between November 2015 and June 2016, the SAB Survey canvassed district superintendents and state officials across the country to collect the boundaries for their schools (Geverdt, 2018). As children age, schools become a central feature of their community, existing within neighborhoods that are defined by their SAB. SABs were chosen over other neighborhood definitions because of their direct relationship between schools and the surrounding geographic area. Without access to student addresses, SABs provided a way to group children and delineate neighborhoods around each elementary school. Thus, this study used these school boundaries as the geographical organizer for the neighborhoods where students live. A map of SABs across Virginia is shown below in Figure 1.

TABLE 1 Overall school readiness rates and by domain.

Readiness status	Overall
Ready	44,977
Not Ready	35,140
Total	80,117
% Ready	56.1
Missing	4,603
Total (missing included)	84,720
% Missing	5.43

*998 and 467 students dropped due to missing characteristic data and missing readiness data on any domain, respectively.

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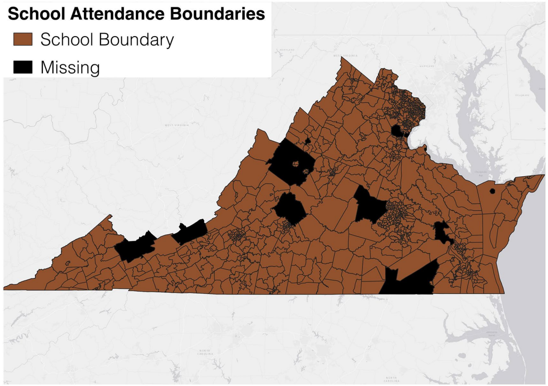

FIGURE 1
School attendance boundary map, Virginia 2015.

Neighborhood conditions

Neighborhood opportunity

The *Child Opportunity Index* (COI) 2.0 was used to measure availability of resources and conditions that matter for children's healthy development (Noelke et al., 2020). The COI 2.0 is a census tract-level index of 29 indicators that measure place-based resources such as access and quality of early childhood education, green space, access to healthy foods, toxin-free environments, and socioeconomic resources. The 29 indicators are grouped into one overall state-normed composite score. This overall score ranges from 0 to 100 with higher scores indicating higher resourced neighborhoods (Diversitydatakids.org, 2022). The COI is strongly correlated with measures of intergenerational economic mobility from the Opportunity Atlas and measures of health and life expectancy (Acevedo-Garcia et al., 2020).

To join the COI at the census-tract level with the SABs, the geographical map of the 2015 SAB Survey was overlaid with the 2015 census tract map using geospatial analysis and calculated the percent, p, of each tract contained within an SAB (U.S. Census Bureau, 2016; National Center for Education Statistics, 2018). These percentages were then used to weight the overall COI score of each census tract t contained within an SAB, s, to calculate an SAB-wide weighted average COI score as shown in Equation 1.[1] A map of the weighted average COI across Virginia is shown below in Figure 2.

$$\text{SAB - wide weighted average COI for SAB, } s = \frac{\sum_{t=1}^{k} (p)_{st} {}^{*} (\text{COI})_{st}}{\sum_{t=1}^{k} (p)_{st}} \quad (1)$$

1 Excluded from these calculations were any tract with less than 0.2% of its area contained within the SAB. Further, 40 SABs were randomly selected to manually verify the number and weight of each tract within each SAB.

Neighborhood segregation

In addition to measures of neighborhood resources, the COI 2.0 contains data on the racial/ethnic composition of children ages 0–5 years living in a census tract. Applying the formula in Equation 1 to these data, the total number of children by race/ethnicity within an SAB was calculated. This weighted value was then used to generate three measures capturing the level (overall) and type (race-specific) of residential segregation present within the SAB. While all the measures capture residential racial segregation, each provide a unique lens through which to view it. In the following sections we both describe each measure and its unique advantage relative to the others.

The first segregation measure (*Entropy*) is an entropy index, or Theil's H, which calculates the relative distribution of races/ethnicities within an area. Entropy thus allows us to capture the effect of "overall" segregation irrespective of the dominant group. This index, shown in Equation 2, relied on the total population of an SAB and the share of five major racial groups (Asian, Black, Hispanic, White, and two or more races). The "Other" racial group was not included due its small share of the population

$$\text{SAB - wide entropy index for SAB, } s = -\sum_{j=1}^{5} h_{sj} {}^{*} \ln\left(h_{sj}\right) \quad (2)$$

In this case, h_{sj} is the share of ethnicity j in the SAB. Higher scores indicate the SAB has more equal representation of these racial/ethnic groups, while lower scores indicate more racially/ethnically homogenous SABs. To examine how the relationship between COI and school readiness varies with neighborhood segregation, SABs were divided into three levels of segregation according to their entropy index value: High Segregation (below the 25th percentile), Medium Segregation (25th–75th percentile), and Low Segregation (above the 75th percentile).

The second and third measures of segregation capture the level of segregation between marginalized (Black/Hispanic) and non-marginalized (White/Asian) students. Here we were interested in not only if segregation was impactful, but whether this effect varied depending on the racially dominant group in the segregated area. The existing literature shows a significant difference in other neighborhood conditions and effects on student outcomes from segregation across racial/ethnic lines. Consistently these studies found that segregated communities of color had on average worse living conditions that matter for child development and educational opportunities than segregated White areas (Quillian, 2014; Shedd, 2015; Frankenberg, 2016; Owens, 2020; Hardy et al., 2021). That is to say, a segregated area of marginalized children is systematically different from a segregated area of non-marginalized children. Thus, the second measure of segregation (*Exposure*) uses an exposure (or isolation) index to identify segregated SABs. The exposure index represents the probability that a child of one group was likely to interact with someone of another group

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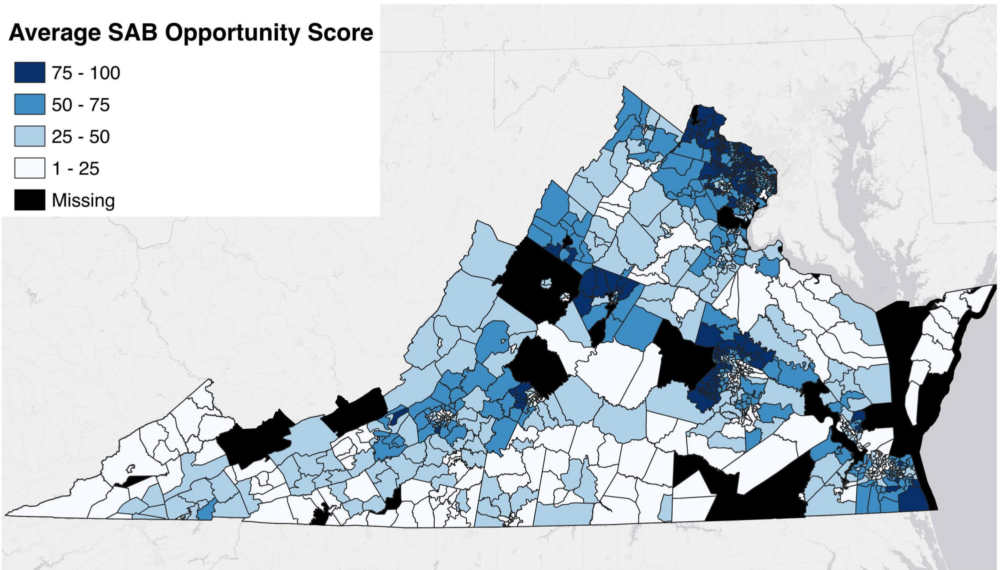

FIGURE 2
Weighted average COI score, by 2015 Virginia school attendance boundary.

within that tract prior to entering kindergarten (Forest, 2005). The Exposure measure is unique among our segregation metrics in that it is the only one we calculated at the tract level. This provides a more geospatially nuanced understanding of the level of cross-racial interactions expected in a community. The equation is shown in Equation 3.

$$\text{Tract - wide exposure index for Group 1 in SAB, } s = \sum_{t=1}^{k} \frac{n_{t1}}{n_{s1}}^{*} \frac{n_{t2}}{n_t} \quad (3)$$

Where s_1 is the population of children in group 1 in SAB, s, and n_t is the total population of children in tract, t. n_{t1} is the number of children in group 1 and n_{t2} was the number of children in group 1 and group 2 in t. From this general equation, two indices were created. One where group 1 are Black and Hispanic children and group 2 are White and Asian children and another that reverses these groupings. Each index then captured the likelihood of group 1 being exposed to group 2. Each census tract was assigned an index score which was then averaged across the SAB to create a SAB-wide value using Equation 1. Again, to answer this study's research questions, SABs were categorized as being Segregated Black/Hispanic communities (Black/Hispanic exposure index values in the lowest 10th percentile, i.e., least likely to interact with a White or Asian child), Segregated White/Asian communities (White/Asian exposure index values in the lowest 10th percentile, i.e., least likely to interact with a Black or Hispanic child), or Not Segregated.

The third segregation measure (*Share*) identifies Segregated Black/Hispanic or White/Asian SABs based on the proportion of these groups within the SAB. Conceptually, this aligns the most with the general population's notion of what makes an area segregated. SABs with a share of Black and Hispanic or White and Asian children in the 90th percentile were categorized as Segregated Black/Hispanic or White/Asian, respectively. As shown in Table 2, these methods resulted in a comparable number of SABs and students identified in Segregated Black/Hispanic and White/Asian SAB. These numbers also corresponded to a roughly equal number of High Segregation SABs using the Entropy measure.

Student characteristics

Student demographic characteristics were collected by the Virginia Department of Education (VDOE) and drawn from Student Record Collection data entered and updated by school division personnel each fall (Virginia Kindergarten Readiness Program, 2019). The category race/ethnicity included Asian, Black or African American, Hispanic/Latino of any race, White, and two or more races, and Other (American Indian or Alaska Native, Native Hawaiian, or other Pacific Islander). Preschool experience was a state-assigned code to identify a student's most recent pre-K experience. Students from low-income backgrounds were identified as economically disadvantaged if at any point during the school year the student was eligible for Free/Reduced Meals or Medicaid and/or received TANF. English Learner (EL) students were identified using the VDOE EL Code and whether they received EL services or were within 40 years of exiting EL services. Students were coded as having a disability if any VDOE Disability Code was present except Qualified Individual under Section 504. These data were merged with VKRP data.

TABLE 2 School readiness rate and student race and ethnicity by segregation type and level.

Segregation type and level	*N* SAB	*N* students	Mean school readiness rate	Mean % Asian	Mean % Black	Mean % Hispanic	Mean % White
Entropy							
Low Segregation	259	26,187	53.01	9.1	18.9	20.5	34.9
Medium Segregation	518	42,267	55.90	4.0	20.2	12.0	52.6
High Segregation	257	16,266	58.71	0.7	12.1	3.5	79.6
Exposure							
Not Segregated	831	71,158	56.59	5.2	14.8	13.3	54.6
Segregated Black/Hispanic	100	7,928	46.01	1.0	60.5	12.9	16.3
Segregated White/Asian	103	5,634	59.65	2.0	1.5	0.82	94.0
Share							
Not Segregated	828	70,870	56.73	5.2	14.7	13.0	55.1
Segregated Black/Hispanic	103	8,263	45.46	1.2	59.9	15.4	13.2
Segregated White/Asian	103	5,587	59.38	1.9	1.3	0.82	94.2

SAB, school attendance boundary.

Analytic approach

Both research questions examined whether neighborhood resources were correlated with a child's likelihood of being overall school ready, or school readiness likelihood. To answer each, a series of logistic regressions were estimated that predicted whether a student was ready for school as defined by the statewide readiness assessment. The key explanatory variable for the analyses was the standardized weighted average SAB COI score.

The base model specification, given in Equation 4, generated results to answer research question 1. This model predicted the likelihood student *i* in SAB *s* was school ready as a function of the weighted average COI in the student's SAB and the student's characteristics. The coefficient β_1 was the coefficient of interest. It represented the change in school readiness likelihood associated with an additional one standard deviation increase to COI, controlling for student characteristics (i.e., race/ethnicity, gender, pre-K experience, English Learner status, economically disadvantaged status, and disability status).

$$\text{PR}\left(\text{KR}_{is}\right) = \frac{1}{1+e^{\beta X}} \quad (4)$$

where $\beta X = \beta_0 + \beta_1 \text{COI}_s + \theta'\left(\text{Student Chars}\right)_i$

One assumption of the logit model is linearity between the log odds of the dependent variable and continuous variables. Each model only included one continuous variable, SAB-overall COI score. Nonlinearity was tested using kernel density and by running models including both the score's natural and higher order forms. Neither of these tests supported the presence of functional form misspecification (Stoltzfus, 2011). The presence of outliers and multicollinearity were also tested using the Pregibon Delta Beta Statistic test and Variance Inflation Factor, respectively. Both tests strongly suggested that neither were a concern (UCLA Statistical Consulting Group, 2006; Akinwande et al., 2015).

Next, each measure of community segregation (Entropy, Exposure, and Share) was added to the base model one at a time, as shown in Equation 5. Due to high correlations among the segregation types, separate models were run for each variable. For each measure, two of the three levels were added as indicators (i.e., Low and Medium Segregation for the Entropy measure and Segregated Black/Hispanic and Segregated White/Asian for the Exposure and Share measures). These models test the association between COI and school readiness change when controlling for community segregation (comparing the β_1 coefficients from Equations 4, 5). Interaction terms were then added between the community segregation variables and COI to assess how the association between COI and school readiness varies with community segregation.

$$\text{PR}\left(\text{KR}_{is}\right) = \frac{1}{1+e^{\beta X}} \quad (5)$$

Where
$\beta X = \beta_0 + \beta_1 \text{COI}_s + \beta_2 Seg1_s + \beta_3 Seg2_s + \theta'\left(\text{Student Chars}\right)_i$

Reporting results

To facilitate the interpretation of these models' findings, the results were reported as odds-ratios which show the change in likelihood of the student being school ready relative to a baseline, holding all else constant. In all models, standard errors were reported that were robust to the clustering of students within SABs. Furthermore, presented are two sets of predicted probabilities that the average student is school ready when in an SAB with a COI one-half of a standard deviation below the mean and when in a SAB with a COI one-half of a standard deviation above the mean. These predicted probabilities were provided for each segregation type and level.

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These predicted probabilities for an average student were defined in two ways. The first was the average student among all students (aka Grand). These probabilities were predicted holding all other variables constant at their analytic sample mean. The second was the average student within a segregation type and level (aka Group). Here, the predicted probabilities held all other covariates at their mean within a given segregation type and level. The results from each prediction differ from one another as the two means correspond to two different points along the nonlinear estimates produced by the logit model. Each set of predictions offered unique advantages and disadvantages to the analyses. While the Grand means allowed for comparisons where the only difference was the segregation level, it belied the significantly different student characteristics within each type of segregation previously shown in Table 1. Conversely, using Group means limits the ability to compare effects across segregation levels, but allows for testing the predicted change for the average student within that segregation level.

Results

Descriptive statistics

Students were racially (6.9% Asian, 20.8% Black, 17.6% Hispanic, 47% White, and 7% two or more races), socioeconomically (38% identified as economically disadvantaged), and linguistically (15% English Learner) diverse. The children in the sample also had a breadth of preschool experiences. Over 77% of students had some preschool experience, with the majority in public (34%) and private/daycare (36%) programs. Readiness rates by student characteristics are shown in Table 3.

As shown earlier in Table 2, significant differences existed between the average SAB readiness rate across segregation levels within the overall and two race-specific segregation variables. First, comparing school readiness using Entropy levels, the mean readiness rate in High Segregation SABs was nearly 11% greater than that of the most diverse SABs. However, when arranging SAB by their race-specific type of segregation, the mean readiness rate in White/Asian segregated SABs were between 30% (Exposure) to 33% (Share) greater than those in Black/Hispanic segregated schools. Additionally, a significant difference was found in the student racial composition at each neighborhood opportunity level. As shown in Figure 3, Black students were overrepresented in low-resourced SABs, while White and Asian students were overrepresented in the highest resourced areas.

Is a child's likelihood of being school ready associated with the neighborhood opportunity within their school attendance boundary?

Neighborhood opportunity was, on average, positively associated with a student's school readiness in the fall of kindergarten. The analysis found that a student in a higher-resourced SAB was 8.4% more likely ($p < 0.001$) to demonstrate school readiness skills than a similar student in a lower-resourced SAB (see Table 4, Model 1). This change corresponds to an increase in expected likelihood of school readiness from 55.4% to 57.4% (2 points or 3.6%).

TABLE 3 School readiness rates by student demographic groups.

Student demographics	*N*	%	% ready (Non-missing)	% ready (All)
Total students	84,720		56.1	53.1
Total schools	1,034			
Gender				
Female	41,307	48.8	62.4	59.2
Male	43,413	51.2	50.2	47.3
Race/Ethnicity				
Asian	5,897	6.9	66.3	62.3
Black	17,589	20.8	47.1	45.4
Hispanic	14,923	17.6	41.6	36.8
White	39,976	47.2	63.2	60.6
2 or more	5,954	7.0	59.6	57.2
Other	381	0.5	53.2	48.6
Disadvantaged				
Disadvantaged	32,182	38.0	44.4	41.3
Not disadvantaged	52,538	62.0	63.2	60.3
Disabled				
Disabled	7,431	8.8	34.4	30.4
Not disabled	77,289	91.2	58.1	55.3
EL Status				
EL	12,699	15.0	35.7	30.5
Not EL	72,021	85.0	59.4	57.1
Pre-K experience				
No PK	19,447	23.0	41.5	38.3
Headstart	3,905	4.6	45.1	43.3
Public	28,823	34.0	53.6	50.1
Private/Daycare	30,470	36.0	68.7	66.6
Dept. of defense	653	0.8	54.3	53.0
Family home	1,422	1.7	57.1	55.8

*998 and 467 students dropped due to missing characteristic data and missing readiness data on any domain, respectively.

Does the association between school readiness and neighborhood opportunity within a child's school attendance boundary vary by residential segregation?

To answer the second research question, the models included each segregation variable – Entropy (or overall segregation), Exposure, and Share – along with student characteristics as covariates, as described in Equation 5, before interacting segregation levels with COI. Results from the non-interacted models are displayed in Table 4 (Models 2–4) as

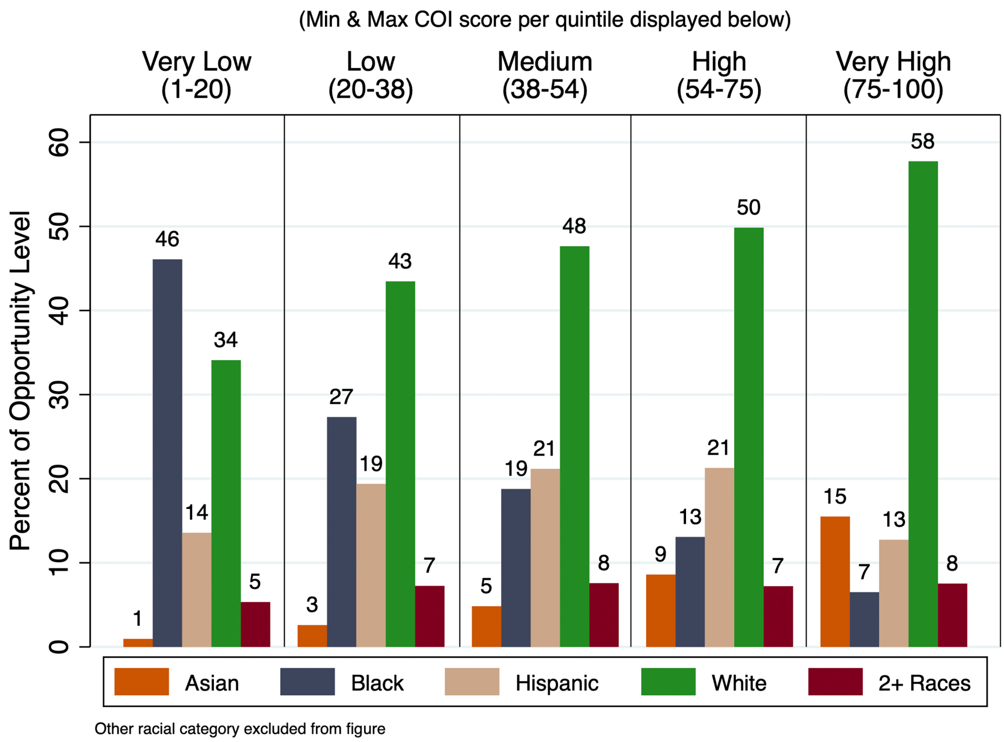

FIGURE 3
Share of observed students by race/ethnicity and COI level.

odds-ratios. The first important finding from these models is that the estimated relationship between COI and school readiness changed very little when any of the segregation types were added to the model. Second, there was little to no difference in average school readiness rates between SABs with different levels of segregation. With respect to the Entropy measure of segregation, a student's likelihood of being school ready is 8.9% lower ($p < 0.05$) in a Low Segregation community than in a High Segregation community. There were no statistically significant differences in predicted readiness rates between Medium and High Segregation communities or between communities using either the Exposure or Share measures of segregation.

Including interactions between the SABs' segregation and COI, however, showed that segregation in the community moderated the relationship between neighborhood opportunity and school readiness (Table 5). Again, the results from the model including the Entropy measure tell a more complex story. The main effects for segregation now refer to a neighborhood with average conditions (COI). The readiness rates in Medium and Low Segregation communities with average neighborhood opportunity were statistically lower than in High Segregation communities with average neighborhood opportunity (8.4% and 10.2% less likely, $p < 0.01$ and $p < 0.05$, respectively). Next, this study explored the interaction effect of a one standard deviation (SD) increase in COI with each of the segregation levels. Students in a higher-resourced High Segregation SAB had a school readiness likelihood 19% higher ($p < 0.001$) than their peers in a lower-resourced, but similarly segregated SAB. Among Medium Segregation SABs, students in higher-resourced neighborhoods were 5.4% more likely ($p < 0.05$) to be school ready. The same difference among Low Segregation SABs was 7.6% ($p < 0.05$). The change in school readiness likelihood from increased neighborhood resources was also significant between Medium and Low Segregated SABs. While students in less segregated SABs continued to exhibit a lower school readiness likelihood than those in High Segregation areas, the relationship between neighborhood opportunity and school readiness was greatest in the High Segregation communities.

The pattern of differences across community segregation levels in how neighborhood opportunity was related to school readiness with the Entropy measure was echoed with the Share measure. An additional one standard deviation of improved neighborhood opportunity in Segregated Black/Hispanic communities was associated with a 45.3% higher ($p < 0.001$) school readiness rate compared to a 7.6% higher ($p < 0.001$) rate in Not Segregated SABs. The coefficient suggests the relationship between neighborhood opportunity and school readiness was larger in Segregated White/Asian communities than in Not Segregated communities; however, the study lacks sufficient precision to be confident. The results from the model that included the Exposure measure of segregation found no differences in school readiness rates across communities of different segregation types with average neighborhood

TABLE 4 Estimated coefficients as odds ratios from models predicting school readiness.

	Model 1 Base	Model 2 + Entropy	Model 3 + Exposure	Model 4 + Share
SAB COI (Standardized)	1.084***	1.089***	1.082***	1.088***
	(0.019)	(0.020)	(0.021)	(0.021)
Asian	1.435***	1.463***	1.442***	1.438***
	(0.065)	(0.066)	(0.066)	(0.066)
Black	0.623***	0.634***	0.631***	0.625***
	(0.017)	(0.017)	(0.017)	(0.017)
Hispanic	0.730***	0.744***	0.735***	0.733***
	(0.022)	(0.022)	(0.022)	(0.022)
Two+ Races	0.893***	0.906**	0.898**	0.896***
	(0.030)	(0.030)	(0.030)	(0.030)
Other	0.769*	0.783*	0.774*	0.771*
	(0.089)	(0.091)	(0.090)	(0.089)
Female	1.628***	1.627***	1.628***	1.628***
	(0.027)	(0.027)	(0.027)	(0.027)
Econ disadvantaged	0.657***	0.655***	0.656***	0.656***
	(0.014)	(0.014)	(0.014)	(0.014)
Disability	0.347***	0.347***	0.346***	0.347***
	(0.011)	(0.011)	(0.011)	(0.011)
EL	0.446***	0.451***	0.447***	0.446***
	(0.017)	(0.017)	(0.017)	(0.017)
Headstart PK	1.332***	1.320***	1.328***	1.331***
	(0.065)	(0.064)	(0.064)	(0.064)
Public PK	2.143***	2.139***	2.142***	2.142***
	(0.061)	(0.061)	(0.061)	(0.061)
Private PK	2.049***	2.056***	2.051***	2.050***
	(0.057)	(0.057)	(0.057)	(0.057)
DoD PK	1.214*	1.230*	1.215*	1.219*
	(0.117)	(0.119)	(0.117)	(0.117)
Family day home	1.448***	1.456***	1.448***	1.450***
	(0.083)	(0.083)	(0.083)	(0.083)
Medium segregation		0.930+		
		(0.038)		
Low segregation		0.911*		
		(0.042)		
Segregated Black/Hisp			0.970	1.021
			(0.052)	(0.056)
Segregated White/Asian			1.049	1.049
			(0.076)	(0.076)
Constant	0.975	1.020	0.962	0.960
	(0.028)	(0.042)	(0.029)	(0.029)
Observations	80,117	80,117	80,117	80,117
Pseudo R^2	0.0859	0.0860	0.0859	0.0859

Robust standard errors in parentheses.
*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; + $p < 0.1$.

TABLE 5 Selected estimated coefficients as odds ratio from models predicting school readiness.

	Overall	Race-specific	
	Entropy	Exposure	Share
SAB COI (Standardized)	1.192***	1.074***	1.076***
	(0.041)	(0.022)	(0.022)
Medium Segregation†	0.916*		
	(0.039)		
Low Segregation†	0.898*		
	(0.042)		
Segregated Black/Hispanic†		1.124	1.441***
		(0.144)	(0.150)
Segregated White/Asian†		1.053	1.048
		(0.081)	(0.081)
Medium Segregation * SAB COI (Standardized)	0.884**		
	(0.037)		
Low Segregation * SAB COI (Standardized)	0.903*		
	(0.043)		
Segregated Black/Hisp * SAB COI (Standardized)		1.149	1.350***
		(0.114)	(0.109)
Segregated White/Asian * SAB COI (Standardized)		1.031	1.021
		(0.084)	(0.084)
Observations	80,117	80,117	80,117
Pseudo R^2	0.0864	0.0860	0.0862

All variables include student characteristics as listed in Model 1 of Table 4. Robust standard errors in parentheses.
*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; + $p < 0.1$.
†Coefficient represents effect size at mean COI (Main Effects).

opportunity nor that the relationship between neighborhood opportunity and school readiness differed with community segregation.

To assist the interpretation of these changes in likelihood ratios, the predicted school readiness rates in communities defined by the three segregation measures are presented which assign neighborhood opportunity one-half standard deviations below and above the means (Table 6). The predictions for the two types of average students (Grand and Group) as described earlier are shown. Across the segregation measures, more segregated, and particularly Segregated Black/Hispanic, SABs showed a greater increase in predicted school readiness than Low or Not Segregated SABs. While the Grand predicted values suggested that students were most likely to be ready for school in Segregated Black/Hispanic SABs – a significant departure from the related literature – this merely reflects the process of holding all other covariates at the analytic sample mean. To better account for the effect of COI on the average student in each level, the Group predicted values were then used. Again, more segregated SABs consistently showed greater change from increasing COI. Further, despite the average student in a lower-resourced Segregated Black/Hispanic SAB having a school readiness likelihood far below the average student within the other segregation levels at the same COI, the gap was dramatically reduced by increasing neighborhood opportunity.

TABLE 6 Change in predicted school readiness likelihood by interaction term.

	Predicted school readiness probability		Change in predicted probability from +1 SD COI	
	At COI = −0.5	At COI = +0.5	Percentage points	%
Grand[a]				
Entropy				
High segregation	56.2	60.5	4.3***	7.7
Medium segregation	55.6	56.9	1.3*	2.3
Low segregation	54.8	56.6	1.8*	3.3
Exposure				
Not segregated	55.5	57.3	1.8***	3.2
Segregated Black/Hispanic	56.7	61.8	5.1*	9.0
Segregated White/Asian	56.4	58.9	2.5	4.4
Share				
Not segregated	55.4	57.2	1.8***	3.2
Segregated Black/Hispanic	60.6	69.1	8.5***	14.0
Segregated White/Asian	56.3	58.6	2.3	4.1
Group[b]				
Entropy				
High segregation	58.9	63.0	4.1***	7.0
Medium segregation	55.9	57.2	1.3*	2.3
Low segregation	52.6	54.4	1.8*	3.4
Exposure				
Not segregated	56.0	57.8	1.8***	3.2
Segregated Black/Hispanic	48.8	54.0	5.2*	10.7
Segregated White/Asian	60.9	63.3	2.4	3.9
Share				
Not segregated	56.1	57.9	1.8***	3.2
Segregated Black/Hispanic	51.3	60.5	9.2***	17.9
Segregated White/Asian	60.7	62.9	2.2	3.6

Predictions from models presented in Table 5.
[a]All other variables in the models held constant at the mean among all students.
[b]All other variables in the models held constant at the mean among students in SABs of the specific segregation type and level.
***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; $^{+}p < 0.1$.

As shown in Figure 4, in the Share model, this growth in school readiness likelihood propelled the average student in a Segregated Black/Hispanic SAB past that of the average student in a Not Segregated SAB.

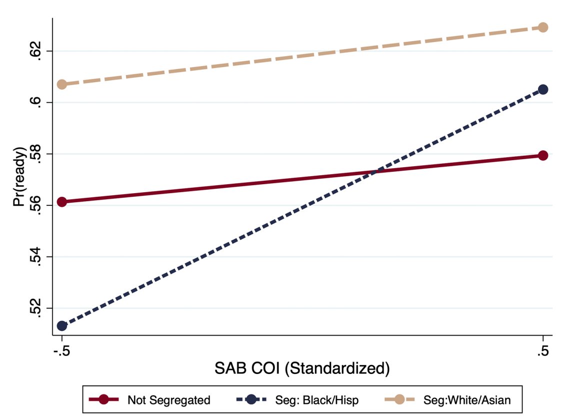

FIGURE 4
Predicted school readiness likelihood for average student, by segregation level (share).

Discussion

This study aimed to expand our understanding of the intersection between children's school readiness and neighborhoods conditions, including neighborhood opportunity and racial segregation, at-scale within a state and utilizing novel geospatial data and techniques. Results point to several key findings. First, neighborhood opportunity relate to differences in the skills children start school with, and access to opportunity varied by race. Specifically, Black and Hispanic children are overrepresented in low resourced neighborhoods, and White and Asian children overrepresented in higher resourced ones. Further, a community's racial composition, above and beyond the level of neighborhood opportunity, additionally contributed to the differences in children's school readiness at the beginning of kindergarten. Findings suggest possible program and policy directions to enhance children's school readiness and will be explored in more detail below.

Community investment in neighborhood opportunity relate to children's school readiness

Results of this study showed consistent evidence that students living in higher-resourced neighborhoods had higher school readiness skills at the start of kindergarten than those in lower-resourced neighborhoods. These results reinforce existing literature relating neighborhood conditions to academic outcomes (Vaden-Kiernan et al., 2010; McCoy et al., 2015) and expand on newer research investigating neighborhoods and early childhood outcomes (Wei et al., 2021; McCoy et al., 2022). Further, while prior research has shown a strong association between children's family income level and children's school readiness skills at kindergarten entry (Isaacs, 2012; Reardon and Portilla, 2016; Latham, 2018), the current study found that utilizing a more comprehensive measure of neighborhood conditions matters for school readiness, as well. Thus, systemic features play a role in children's school readiness skills at kindergarten entry. With this knowledge, future research should evaluate the extent to which higher-resourced neighborhoods may mitigate school readiness gaps and act as a protective factor for low-income students.

Again, it is important to note that results showed a significant overrepresentation of marginalized and non-marginalized children in low- and high-resourced neighborhoods, respectively. These findings align with other recent research that indicated that access to highly resourced neighborhoods varies by children's race and ethnicity (Hardy et al., 2021). As a result, inequitable access to essential neighborhood resources and opportunity may partially explain the racial/ethnic school readiness gap. While this study did not examine the interaction between children's race and COI with school readiness skills, future research is needed to see if higher-resourced neighborhoods serve as a protective factor for students of color.

Segregation adds another element to school readiness

Two out of the three segregation measures found that, holding all else constant at the average COI, racial residential segregation among zero-to-four-year-olds was correlated with the likelihood of demonstrating school readiness skills. Importantly, the level and type of residential racial segregation, in combination with neighborhood opportunity, also mattered for children's school readiness skills. Results using the Entropy model indicated that the effect of COI on school readiness grew with each ascending level of segregation. That is, the change in a student's predicted school readiness likelihood from increased community resources was smallest for Low Segregation SAB and greatest in High Segregation SAB. This finding implies that improving community opportunity in highly segregated neighborhoods may help young children be more ready to enter school. Further, results from the Share model showed a greater effect for students in predominantly marginalized communities. Students from Segregated Black/Hispanic neighborhoods were predicted to be much less likely to be ready for school than students from Not Segregated and Segregated White/Asian neighborhoods at the lower-resourced neighborhood level. This model also indicated that students in Segregated Black/Hispanic neighborhoods saw the greatest gains to their school readiness likelihood from an increase in COI. In other words, neighborhood opportunity seems to play a significant role in school readiness for children from Segregated Black/Hispanic SABs. This finding corresponds to recent research on the importance of accessible and equitable neighborhood resources (Wei et al., 2021), especially for children from marginalized communities (Hardy et al., 2021). While these results should be interpreted cautiously, the patterns suggest that improving neighborhood opportunity could serve as an avenue for remedying gaps in children's school readiness skills.

Interestingly, the predicted probabilities from both the Entropy and Share segregation models show that, holding all else constant at either the Grand or Group means, a student from a more segregated SAB was more likely to have higher school readiness skills at the start of kindergarten. This finding diverged from expected results, given that the literature suggested that less racial segregation may lead to better student outcomes. Previous research found that children who experience diverse and integrated early childhood settings were more likely to have positive academic and social outcomes (Reid and Kagan, 2015; Wells et al., 2016; McArdle and Acevedo-Garcia, 2017). For instance, children who were exposed to a diverse classroom were more likely to have improved critical thinking and problem-solving skills (Wells et al., 2016) and cross-racial friendships (Aboud et al., 2003). Further, being exposed to racial diversity at a young age may help counter racial prejudice and implicit bias later in life (Cloutier et al., 2014; Reid and Kagan, 2015). While some research suggests that higher levels of segregation may have the potential to serve as a protective factor for children of color, particularly if children's early childhood teachers are the same race as them (Downer et al., 2016; Redding, 2019; Wymer et al., 2022), the majority of the more segregated SABs in the Entropy model were disproportionately White neighborhoods. As such, it is difficult to speculate possible underlying mechanisms that may play a role in the association given this sample. Thus, as this is one of the first studies to examine the role of segregation and neighborhood opportunity on school readiness skills, more research is needed to parse out this association.

One possible explanation for this unexpected finding may be that children's experiences of segregation may vary based on urbanicity, shifts in demographics, and location. Virginia is a fairly segregated state, and recent research indicates that racial segregation remains high across and within school districts, especially at the elementary school boundary zone level (Siegel-Hawley et al., 2020). Urbanicity may also play a role in children's experiences of racial segregation, as students are unevenly distributed by race across the state. White students predominantly

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make up a larger share of school enrollment in Virginia's rural areas, whereas students of color are more concentrated in urban and suburban settings (Siegel-Hawley et al., 2020). Many neighborhoods in Virginia have also seen a shift in demographics over the past decade, as people of color now make up the majority of people under 18 in the Commonwealth (U.S. Census Bureau, 2020). These shifts in demographics have led to school enrollment changes, such that students of color now make up the majority of student enrollment in Virginia (Siegel-Hawley et al., 2020). Research also suggests that as neighborhood racial composition changes, school boundary zones may, as well. A case study of Loudoun County Public Schools, an affluent Washington, D.C. suburb, found that as the county grew more diverse, the district's attendance zones became more gerrymandered (Richards, 2014). Finally, regional differences may also play a role in children's experiences of racial segregation. Rural areas make up a majority of the state's geography, while urban and suburban pockets are primarily located in the state's northern, central, and southeastern regions. Thus, future research could employ geospatial analysis techniques to locate and compare neighborhoods from different areas around the state to examine regional variation in racial segregation.

Limitations and future directions

There are several key limitations that affect the current findings. First, the use of a dichotomous outcome reduces both the power and validity of this study. As mentioned earlier in this study, this binary outcome was chosen to be consistent with the VDOE definition of school readiness which carries significant policy relevance. Analytically, however, an equally reliable continuous school readiness variable would result in stronger and more robust findings.

Next, lacking student addresses, the analysis is reliant on SAB-wide averages for neighborhood opportunity and demographic values. Such aggregation naturally reduces the analytic precision as well as introduces a multi-level component to an otherwise student-level analysis. Additionally, the process to construct these averages assumes that neighborhood opportunity and demographics are uniformly distributed across both the census tract and SAB. This assumption is almost certainly flawed and likely misrepresents the living conditions in these areas.

Another limitation is the ~4-year gap between the 2015 COI 2.0 and SAB Survey with the 2019 VKRP assessment. This gap opens the door to measurement error if the SAB-level values no longer reflect the actual conditions in these areas. For this not to be an issue, the 2019 SABs must (1) cover the same area as they did in the survey and (2) the COI must be relatively stable over the period. While the latter has yet to be empirically tested, the former is presumably violated as rezoning of SABs has likely occurred since the 2015 survey was collected (Siegel-Hawley et al., 2020). Many school districts in Virginia have started or are considering rezoning their school attendance boundary zones, likely a result of population changes (Siegel-Hawley et al., 2020). Rezoning practices have also primarily affected students of color in Virginia. Among the districts that rezoned, students were still overexposed to same-race peers, especially Black and Latinx students (Siegel-Hawley et al., 2020). Thus, this study may inform Virginia school districts as they consider their attendance boundary rezoning policies.

Additionally, although the composite measure of neighborhood opportunity had a significant association with school readiness, the current study does not evaluate whether particular types of resources have a greater role on school readiness than others. Included in the COI 2.0 are neighborhood indices capturing socioeconomics, health, and education. Future research should investigate whether similar results are achieved using one of these alternative indices to get a more nuanced understanding of how neighborhoods may affect school readiness.

Despite these limitations, study findings provide insights to state and local policymakers to more precisely identify high-need communities and provide the resources and supports necessary to increase equitable access to high-quality early educational opportunities. At a practical level, these findings may help educators and policymakers better understand the needs of children and communities to prepare students for school. Many states use kindergarten readiness assessments, and these findings suggest local and state leaders could use this combination of data to consider the roles neighborhoods and the policies that shape them play in enhancing children's early skills (Regenstein et al., 2017; Olson and LePage, 2021).

Understanding the magnitude of readiness gaps, along with the factors linked to these gaps, can help educators and policymakers support the various systems that affect school readiness. These findings suggest that more targeted and equitable policy decisions could mitigate disparities in students' early childhood experiences, resulting in higher levels of children's school readiness. This opens the door to more kinds of investment, including in communities, as a pathway to more effectively support all young children. Results reinforce an expanding literature suggesting that improving educational equity requires addressing neighborhoods and not just school or classroom conditions. Thus, this study has broad implications for considering who has access to high-quality early childhood neighborhood opportunities, and how to improve access and quality regardless of zip code or race.

Data availability statement

The datasets presented in this article are not readily available because access to student-level readiness assessment data requires a data use agreement with the Virginia Kindergarten Readiness Program. Requests to access the datasets should be directed to Virginia Kindergarten Readiness Program, vkrp@virginia.edu.

Ethics statement

The studies involving human participants were reviewed and approved by Institutional Review Board Social and Behavioral Sciences (IRB-SBS) – University of Virginia. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

TL contributed to the conception for the study, designed and performed the statistical analysis, and primarily wrote the measures, methods, and results sections. JL-C and CC contributed to the conception of the study, wrote the introduction and discussion, and provided input to the methods section. AW, JD, and JW revised and reviewed the manuscript. LM oversaw and revised the methodology and results section. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Reinventing the public square and early educational settings through culturally informed, community co-design: Playful Learning Landscapes

Annelise Pesch[1]*, Karlena D. Ochoa[2], Katelyn K. Fletcher[1], Vanessa N. Bermudez[2], Rachael D. Todaro[1], Julie Salazar[2], Hailey M. Gibbs[3], June Ahn[2], Andres S. Bustamante[2] and Kathy Hirsh-Pasek[1,4]

[1]Department of Psychology and Neuroscience, Temple University, Philadelphia, PA, United States, [2]School of Education, University of California, Irvine, Irvine, CA, United States, [3]Center for American Progress, Washington, DC, United States, [4]Brookings Institution, Washington, DC, United States

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Parisa Parsafar,
Eunice Kennedy Shriver National Institute of Child Health and Human Development (NIH), United States

REVIEWED BY
Gayle McPherson,
University of the West of Scotland, United Kingdom
Caroline Cohrssen,
University of New England, Australia

*CORRESPONDENCE
Annelise Pesch
annelise.pesch@temple.edu

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What if the environment could be transformed in culturally-responsive and inclusive ways to foster high-quality interactions and spark conversations that drive learning? In this article, we describe a new initiative accomplishing this, called Playful Learning Landscapes (PLL). PLL is an evidence-based initiative that blends findings from the science of learning with community-based participatory research to transform physical public spaces and educational settings into playful learning hubs. Here, we describe our model for conducting this research, which is mindful of three key components: community input, *how* children learn best, and *what* children need to learn to be successful in the 21st century economy. We describe how this model was implemented in two PLL case studies: one in a predominantly Latine community and the second in early childhood education classrooms. Furthermore, we describe how research employing our model can be rigorously and reliably evaluated using observational and methodological tools that respond to diverse cultural settings and learning outcomes. For example, our work evaluates how PLL impacts adult–child interaction quality and language use, attitudes about play and learning, and community civic engagement. Taken together, this article highlights new ways to involve community voices in developmental and educational research and provides a model of how science can be translated into practice and evaluated in culturally responsive ways.

This synthesis of our process and evaluation can be used by researchers, policymakers, and educators to reimagine early educational experiences with an eye toward the built environment that children inhabit in everyday life, creating opportunities that foster lifelong learning.

KEYWORDS

guided play, playful learning, informal learning, urban design, education, research–practice partnership, community-based research, human-centered design

Introduction

Children from under-resourced homes often have less access to informal learning experiences (DeWitt and Archer, 2017; Takeuchi et al., 2019) and high-quality language interactions (Hirsh-Pasek et al., 2015; Pace et al., 2017; Golinkoff et al., 2019). Yet, these experiences support the development of skills foundational to science, technology, engineering, and mathematics (STEM) learning and are important predictors of later academic achievement (Ramani and Siegler, 2014; Verdine et al., 2014b; Bustamante et al., 2018; Hanner et al., 2019). Recent scholarship highlights that STEM learning can happen anywhere, in the activities present in a child's daily routine (Ahn et al., 2018; Bustamante et al., 2019). For example, children often spend time with caregivers at the grocery store, walking to school, at the laundromat, waiting for the bus, or in neighborhood parks. These places, among others, often hold significance as spaces families frequently visit, where they gather with others and build community. A reinvention of the public square – community spaces where people gather – that draws on the science of learning offers an innovative way to transform everyday spaces into accessible and inclusive hubs that enable the experiences supportive of children's learning (Hassinger-Das et al., 2021; Hadani et al., 2021).

Playful Learning Landscapes (PLL) is a new initiative that takes what researchers know about child development and embeds these insights into everyday spaces. For example, executive functioning (EF) skills are foundational for later academic achievement (Diamond, 2012; Morgan et al., 2019) and have been the target of intervention work seeking to close educational opportunity gaps (Waters et al., 2021). What if designed environments encouraged families and children to exercise their EF skills in spaces where they already spend time together? PLL offers a way to do this with a game called Jumping Feet (see **Figure 1**). Jumping Feet is a version of the familiar sidewalk game, Hopscotch, with a new design and simple prompts that encourage children to jump onto tiles with one foot where they see two and two feet where they see one, activating the EF skills of inhibition and cognitive flexibility (Hassinger-Das et al., 2020). Jumping Feet was used at the first established PLL called Urban Thinkscape, a bus stop in an under-resourced community in Philadelphia, Pennsylvania, where children and caregivers take advantage of time spent waiting for the bus by playing games that foster important developmental skills, such as EF. In addition to Jumping Feet, Urban Thinkscape includes a puzzle wall activity that supports spatial awareness, a game called Stories that facilitates narrative skills and literacy, and finally, a game called Hidden Figures that encourages children and caregivers to identify shapes in shadows. Each of these activities promotes the development of skills (e.g., spatial skills, narrative development, and making observations) crucial to later academic achievement (Dickinson et al., 2010; Verdine et al., 2014a; Bower et al., 2020).

In addition to cultivating important academic and social skills, Urban Thinkscape was designed to reflect and uphold the surrounding community's cultural values and history. A research–practice partnership (RPP) between university researchers and local grassroots organizations led to a series of town hall-style meetings and focus group sessions where community members voiced their goals and priorities for the space. The community identified and helped secure the lot where Urban Thinkscape stands, which holds important historical significance because of its proximity to where Martin Luther King, Jr. delivered a key speech in 1965. Community feedback further led to the inclusion of Martin Luther King, Jr. as a central image featured on the puzzle wall. After the site was secured and the designs approved, hundreds of community members came together to help build the activities at Urban Thinkscape. This process from start to finish offers a powerful example of the importance of community involvement in RPPs to ensure local representation and ownership of community spaces.

Evaluation of Urban Thinkscape revealed that changing an everyday space where families gather changed behavior in ways that fostered higher quality language and interaction between children and their caregivers. Trained data ambassadors, who were members of the local community, observed the amount of back-and-forth conversation between caregivers and children, the type of language used, and interaction quality. After Urban Thinkscape was installed, observers reported an increase in the amount of conversation between caregivers and children, more frequent use of spatial, numerical, and literacy language, and

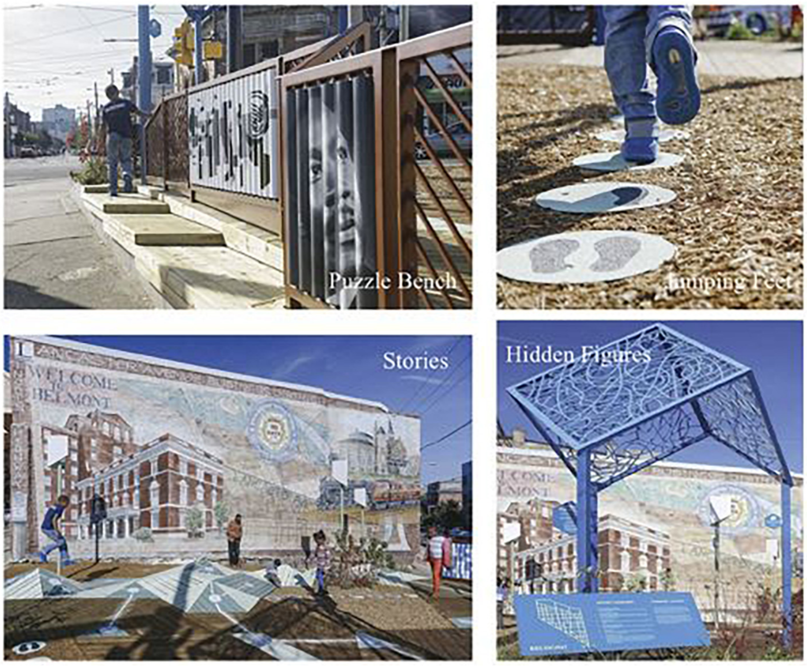

FIGURE 1
Urban Thinkscape installations from Hassinger-Das et al. (2020).

overall higher-quality interactions (Hassinger-Das et al., 2020). These results highlight that PLL impacts how families engage with each other in their local community spaces, and that it can do so with community involvement in culturally responsive and inclusive ways (Todaro et al., 2022).

Urban Thinkscape demonstrated a new way to conduct research by changing physical public spaces in concert with community values and then evaluating how this environmental change impacts caregiver–child interactions and child outcomes known to bolster later cognitive and academic achievement. In this article, we describe our model and process for implementing PLL, which highlights new ways to involve community voices in developmental and educational research. Specifically, we describe how this model was implemented in two PLL case studies, offering examples of extension and refinement of the work to new cultural settings and in the service of different learning outcomes. Finally, we discuss how our model for creating PLLs can be rigorously and reliably evaluated.

The model

Our process for creating PLLs adheres to a new model for conducting developmental and educational research which takes three factors into account: community input and values, the science of *how* children learn, and the science of *what* children need to learn to thrive in the 21st century. In short, this model relies on an equation that melds community and science in ways that foster rich experiential learning and is culturally responsive and inclusive.

Community input

PLL is not the first to discover that everyday spaces can influence human behavior in positive ways. It is the first to build designs informed both by community input and by the science of *how* and *what* children learn. Our method of ensuring community ownership and input in PLLs takes advantage of community-based participatory research (CBPR), an approach to research that involves active and ongoing community partnership (Hacker, 2013; Collins et al., 2018). Community-based participatory research (CBPR) lies on a continuum from projects that are investigator-initiated with partners playing a smaller role to projects where the procedures and methods are co-designed. Most psychological experiments do the former. PLL is an example of the latter in which co-design ensures that community members have an equal voice in informing research protocols, in decision-making, and in the final product of the research (Belgrave et al., 2022), which helps generate community buy-in and participation, and helps secure the longevity of a PLL.

Playful Learning Landscapes (PLL) draws on CBPR principles by eliciting community values, practices, and funds of knowledge and marrying these with principles from developmental science around high-quality learning environments. Activities for PLL are informed by community members through focus-group meetings, surveys, or interviews. These methods provide rich data about community values and practices, such as the importance of family unity or intergenerational learning, that can be intentionally incorporated into PLL designs. In addition, co-design activities, such as having design partners engage in prototype creation with arts and crafts (e.g., *bags of stuff*), can be used to elicit community members' design ideas (Fails et al., 2013; Yip et al., 2013). This also allows researchers to capitalize on community assets and community funds of knowledge to ensure that PLL activities connect with and embody existing community cultural practices (Moll et al., 1992). Our approach thus starts by meeting community members where they are, hearing their concerns, and valuing their input. This part of the model allows our scientific research to be more adaptive to community interests and values.

How children learn

The second part of the equation is brought to the table by the scientific community. Consensus exists in the relatively new *science of learning* (Meltzoff et al., 2009) that children learn best when the learning environment is active, engaging, meaningful, socially interactive, iterative, and joyful (Zosh et al., 2013; Hirsh-Pasek et al., 2015; Weisberg et al., 2016). Foundational to our reinvention of a new type of public square is the curation of activities that embody these six pillars, which together are found in what we call *playful learning*. That is, as part of the design process, we ask whether the PLL will include opportunities for active learning, engagement, meaningful learning, social interaction, iterative learning, and joy.

Playful learning has emerged as a term that describes a continuum, anchored on one end by free play and on the other by direct instruction, which is not play at all, with a range of play types in between, including guided play and games (Zosh et al., 2018; Hassinger-Das et al., 2020). Free play is a child-led and child-initiated experience that generally lacks an intentional learning objective. Direct instruction, on the other hand, has a clear learning objective, but is adult-led and adult-directed, often removing many of the key pillars from the experience (e.g., that it should be active and joyful). Guided play is situated between free play and direct instruction. It capitalizes on the learning pillars by providing children space to direct their learning while borrowing the best of direct instruction by incorporating a target learning goal. That goal can be scaffolded either by gentle guidance and questioning from an adult or through a well-planned and curated environment that supports children's playful exploration, as in PLLs (Zosh et al., 2018).

Compared with direct instruction and free play, guided play holds a privileged spot in the literature in that it often produces strong learning outcomes while capitalizing on children's organic method of engagement with their environment (Hirsh-Pasek et al., 2020; Hirsh-Pasek et al., 2022; Skene et al., 2022). For example, preschool-aged children taught about the properties of different shapes in a guided play condition learned more about the shapes compared with children taught similar information in direct instruction or free play contexts (Fisher et al., 2013). Play-based interventions also reveal the effectiveness of using guided play practices to promote learning. For example, children from under-resourced homes introduced to math concepts using play-based interventions (e.g., games) not only improved but also maintained skills learned through play in the weeks following the intervention (Siegler and Ramani, 2008; Scalise et al., 2018, 2020). A vocabulary play-based intervention for low-income preschoolers was also effective at promoting vocabulary growth when learning was scaffolded by an adult through guided play (Toub et al., 2018). In work with parents, preschool-aged children engaged in more math talk when parents were instructed to supplement a playful game with guided math-based talk compared with parents who did not engage in math-related talk during the play activity (Zippert et al., 2019). When teaching preschoolers fractions, parents who taught using guided play practices reported just as much math talk and more joy compared with those who taught in ways reflecting direct instruction approaches (Eason and Ramani, 2018). These studies highlight how guided play not only promotes learning but also joyful exchanges that promote high-quality interactions between children and their caregivers.

Environments designed to elicit guided play have also been shown to promote children's social and cognitive development. Montessori and Tools of the Mind are two educational approaches that emphasize guided play practices in their curriculum (Montessori, 1964; Bodrova, 1997; Bodrova and Leong, 2007). Both approaches foster child agency in semi-structured playful learning environments where learning is scaffolded by the environment, as in the Montessori model, or by an adult. Preschoolers learning through these approaches show better outcomes on standardized assessments, better EF skills, and more advanced social skills compared with preschoolers in programs that adopt more traditional direct instruction curriculum (Lillard and Else-Quest, 2006; Blair and Raver, 2014; Diamond et al., 2019). These findings highlight that environments, in addition to adult–child interactions, can be intentionally designed to promote the guided play.

What children learn

Finally, the question of what the learning goal should be is central to the design of an installation in PLL. Although children can master content through guided play, educational opportunities that build skills, such as collaboration, communication, content, critical thinking, creative innovation, and confidence (the 6 Cs) are as important as mastering content alone (Darling-Hammond et al., 2020;

Hirsh-Pasek et al., 2020). In fact, there is considerable overlap between 6 C growth and school readiness outcomes. For example, the Early Development Index (EDI), an assessment used to evaluate kindergarten readiness for students residing in Orange County, CA, emphasizes readiness in the domains of language and cognitive development (such as content and communication), communication skills and general knowledge (such as collaboration, critical thinking, and creative innovation), physical wellbeing and motor development, and social and emotional development (such as communication, collaboration, and content). Fostering 6 C growth maps onto the same developmental outcomes that are important for educational success. Thus, environments that foster the 6 Cs set children on a trajectory for academic success and establish the habits of mind that promote lifelong learning.

Applying the model

Engage

Integrating these learning frameworks with community funds of knowledge is a complex process that requires strategic planning and strong partnerships. Implementation of our three-part equation begins by developing RPPs (Penuel and Gallagher, 2017; Farrell et al., 2021) with local community organizations that serve a target population of interest. We engage with community members to identify spaces where they want to see PLLs installed and then co-design activities for the space that reflect the community's priorities, values, and cultural identity. By including members of the community in the design process, PLLs establish connections with the community's cultural practices while elevating community voices and ownership.

For example, our first case study (Case Study 1) applied our model to a new cultural setting in Santa Ana, California. We aimed to deepen community engagement by involving parents and community members in every aspect of our design process. We were connected with parents from the Santa Ana community through an established RPP with trusted community leaders from the Santa Ana Early Learning Initiative (SAELI), a community-led partnership connecting caregivers with non-profit organizations. We worked closely with the founder of SAELI and the existing director, who also envisioned ways in which, as a community, multiple stakeholders could come together to support early learning outcomes for children 0–9 years of age. The importance of connecting with the directors of SAELI cannot be understated. They brought expertise and knowledge about the community and valuable insights about working with local families. They participated in planning meetings and invited us to attend the organization's meetings, from which we learned about their 3-step design framework (namely, Discover and Dream, Design and Destiny, and Sustainability Plan), which we adopted and aligned with Playful Learning Principles in subsequent design sessions. Finally, SAELI leaders connected us with the parents who participated and engaged in our design sessions and continuously supported the process even during the COVID-19 pandemic.

Our second case study (Case Study 2) applied our model to early education settings in the greater Philadelphia area. An RPP was established with a local early childhood education (ECE) network that serves a diverse set of communities. Six early learning centers, serving approximately 50–100 families each, expressed interest in partnering with us. The centers vary by neighborhood and the communities served, which are diverse across religious affiliation, race and ethnicity, and socioeconomic status of students and families. For example, one of the centers focuses on serving predominantly Jewish communities and is located within a synagogue. Another center is located within and affiliated with a local church. Yet, another center is located within the center of the city and predominantly serves children living in downtown Philadelphia. The three remaining centers are located in the surrounding suburbs.

Plan

Once an RPP is established, decisions about the project are co-planned to determine the project timeline, community-engagement activities, and each stakeholder's role in the initiative. Communication about the community's role in the design process ensures transparency and alignment with project goals. For example, community involvement as users, testers, informants, or design partners should be identified and a plan for situating communities in that role established early in the process (Chew et al., 2021).

With the Case Study 1, although our central focus was on co-designing with children and families, other vital stakeholders participated in our design process. For example, the Administrative Service Manager for the City of Santa Ana attended community project meetings, provided feedback on installation prototypes, and highlighted alignment between the current project and existing city projects. Government participation in our project led to city officials indicating their interest in implementing designs co-created with SAELI families into several upcoming park renovation projects. City funding of these projects is allowing us to install PLL in spaces throughout Santa Ana that were previously outside the scope of our research team's budget. Integrating PLL into the city's renovation process further increases the sustainability of the PLL model.

Similarly, although Case Study 2 designs will be installed in classrooms, our team worked closely with 30–40 stakeholders affiliated with our ECE partners, such as key personnel from the program's education and curriculum teams, center directors, health and safety directors, and client relations specialists.

Design

There are several avenues for the co-creation of playful learning spaces, depending on the role(s) community partners assume, which can differ based on funding, project timeline, and project goals. Co-design is an iterative process that capitalizes on community assets and builds on community expertise to optimize children's learning experiences (Bonsignore et al., 2013). Both case studies highlight an approach that involves deep community involvement and illustrate the flexibility of the PLL development process to suit the needs and priorities of partners ranging from city officials to private organizations and to the children and families who subsequently use the installations.

Co-design in Case Study 1 included a series of seven virtual design sessions, led by Spanish-speaking facilitators, where Latine caregivers (n = 36) shared their family and local community experiences. One goal of these workshops was to identify locations for PLLs. Caregivers shared pictures of local spaces and told stories about daily activities they do with their children around the city. As one example, parents expressed their desire to redesign a park in the neighborhood to look more like the plazas of Mexico to pay homage to their cultural heritage. The park became a significant location central to our design activities and planning. Another goal of these workshops was to elicit cultural values and practices and co-design activities to fill these public spaces. Through conversations and structured activities, a core set of cultural values and practices important to families emerged, including intergenerational learning, heritage, and community engagement. With these values in mind, parents created and shared creative prototypes of different installation ideas with the broader group (see **Figure 2**, Panel A). This provided opportunities for parents to collectively create more detailed prototypes and playful game ideas. Our research team met to elaborate on parents' values and designs, assuring that they aligned with learning principles and early STEM concepts, and creating refined prototypes of the PLLs. For example, Lotería bus stop emerged from a mother's spinning wheel design for learning math concepts, which was subsequently refined to model a popular cultural game, Lotería, which incorporates science and math content (see **Figure 2**, Panel D). This design thus leveraged families' collaboration, intergenerational learning, and heritage values through a familiar and enjoyable practice to promote learning through children's observation, prediction, comparison of quantities, and problem solving.

Co-design in Case Study 2 involved three virtual design sessions. Workshops included participants (n = 35) from each of the six participating early learning centers. Community values were elicited in our first design workshop using a "Mad Libs" activity in which participants generated values by brainstorming learning- or principle-related adjectives that were important to them and coalesced around core themes they wanted the installations to invoke. Across the six centers, the core values that emerged from the workshops included diversity, curiosity, inclusion, and an "environment of yes" in which students are encouraged to explore their surroundings (see **Figure 3**). Teachers and center directors shared photographs from their centers of spaces important to them that they wanted to reimagine for their students. In addition, center-specific characters and images were sourced for the designs to capture their unique histories and traditions for "neighborhood flair." For example, the center located within a synagogue selected images related to their cultural heritage, such as Noah's Arc, Moses, and Hebrew letters and words. A suburban center selected images including flags reflecting the diverse international heritages of their teachers and hobbies teachers to partake in like camping and traveling. Teachers and curriculum specialists also provided expert opinions on the learning needs of their students. Science, technology, engineering, and mathematics (STEM) learning goals included: (1) Describe patterns, recognize shapes and numbers, and develop spatial language; (2) Practice investigation and observation skills; and (3) Solve problems using multiple methods. Learning goals for literacy included: (1) Recognize letters and sounds in the alphabet, identify words, and rhyming; (2) Allow children to express themselves through telling stories and dramatic play; and (3) Be curious, observe and describe people, places, and things around them. Finally, design considerations important to the community included: universal designs for learning to ensure students of all ages and ability levels can engage with the installations, flexibility of installment (so they can be relocated as desired), and incorporation of physical motion to allow children to take movement breaks throughout the day.

Approve

Graphic designers and architects then drafted blueprints of the installation(s) based on community input solicited during co-design workshops. Blueprints were subsequently shared with the community for further input and discussion. This feedback loop continued until the final designs were approved by both research and community partners. This process ensured that each installation reflected the community's values and embedded the principles of *how* and *what* of learning (ensuring that all three criteria of our science of learning model's equation were met). Final designs also adhered to a set of considerations consistent with city regulations and best practices (e.g., no loose parts, minimal text, and inviting and engaging design).

In Case Study 1, we undertook an iterative process involving the research team and community members to draft blueprints of PLL installation prototypes. First, our research team conducted an inductive thematic qualitative analysis of co-design meeting transcripts to capture and understand the values and practices of Latine families at home and in their

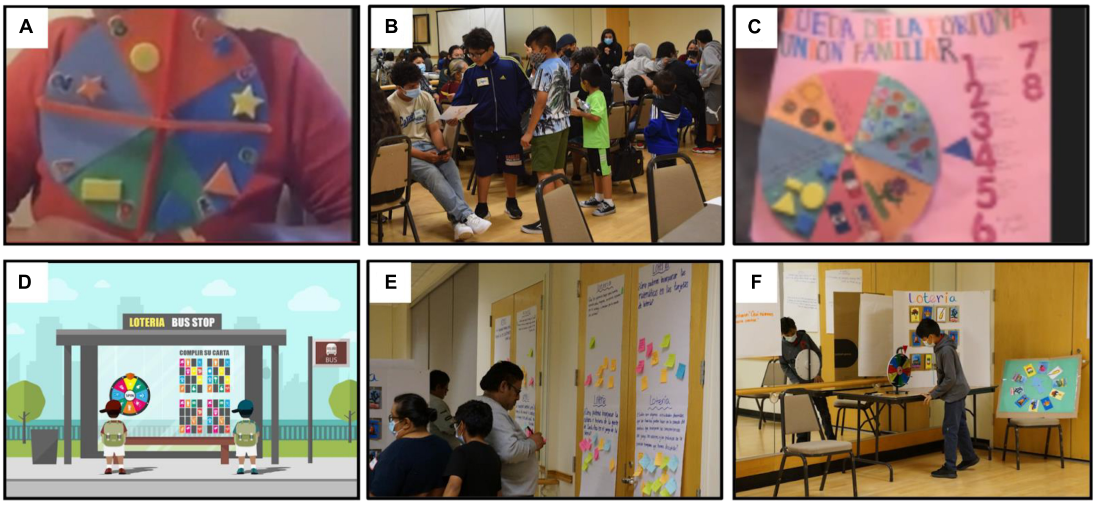

FIGURE 2
Co-design process for creating Playful Learning Landscapes with community members. Pictured here are six iterations of what became the Lotería game bus stop. **(A)** While brainstorming ideas, parents virtually shared their creative prototypes of different playful experiences with the group. **(B)** Parents play-tested their initial prototypes with their children and created new prototypes incorporating children's ideas. **(C)** Next, parents shared their experience playing with their children and introduced their new design in a codesign breakout group, providing opportunities for other parents to give their feedback and collectively create more detailed prototypes and game ideas. **(D)** After much feedback from parents and children, our research team met to elaborate on parents' values and designs, and aligned them to learning principles and early STEM concepts, creating refined prototypes of the PLLs. **(E)** To get feedback on the refined prototypes we asked parents to respond to prompts regarding how we could make the installation culturally relevant to Santa Ana and whether they thought the installations were engaging and meaningful. **(F)** Finally, children and families tested a series of physical prototypes of different PLLs.

community spaces. Next, the research team ($n = 11$) met several times to establish a shared understanding of families' stated values and experiences and review parents' design ideas and prototypes. The research team then selected a subset of parents' ideas and designs to elaborate on and ensured alignment with the science of learning and early STEM learning goals while maintaining parents' values and experiences. Finally, two in-person co-design sessions were conducted with parents ($n = 29$) and children ($n = 54$) where families play-tested life-size mock-ups of PLL designs (see Figure 2, Panel F). To obtain feedback on these refined prototypes, caregivers responded to written and verbal prompts regarding how to make the activities more culturally relevant and how to improve families' experiences using the installations. This iterative process continued until designs were approved and at all points maintained families' values.

An iterative process was also used to create PLL prototypes in Case Study 2. Again here, our research team met several times to process themes from the co-design workshops to create a shared understanding of participants' values and review design ideas and learning goals. Ideas for designs were aligned with the science of learning while still capturing the themes expressed by teachers and center directors during the design workshops. We developed a set of tailored installations designed to focus either on literacy and storytelling or science, technology, engineering, and math (STEM). For example (see Figure 3), several teachers from a center located in downtown Philadelphia expressed their desire to see the city skyline, which was once visible from their rooftop playground but is now eclipsed by a newly-constructed apartment building. At a subsequent workshop, teachers expressed their students' need for opportunities to build phonetic skills including rhyming, sentence structure, and describing characters and settings in narratives. By the third workshop, in collaboration with designers, we designed an interactive skyline rooftop mural to fit their playground, embedded with rhyming words and images, and supplemented with verbal prompts to describe the city (see Panel C, Figure 3).

Build

We began the process of fabrication and installation once the designs were approved by all key stakeholders. In both case studies, local fabricators and architects were prioritized as yet another way to include businesses from the target community in the creation of these PLLs. Where appropriate, community members were invited to help with the fabrication and installation process (e.g., Urban Thinkscape; Hassinger-Das et al., 2020).

In summary, these two case studies illustrate how our model can be refined and applied to new cultural contexts (e.g., a largely Hispanic/Latine community in CA) and settings (e.g., early learning centers). Even during the COVID-19 pandemic, which placed immense stress on communities and educators,

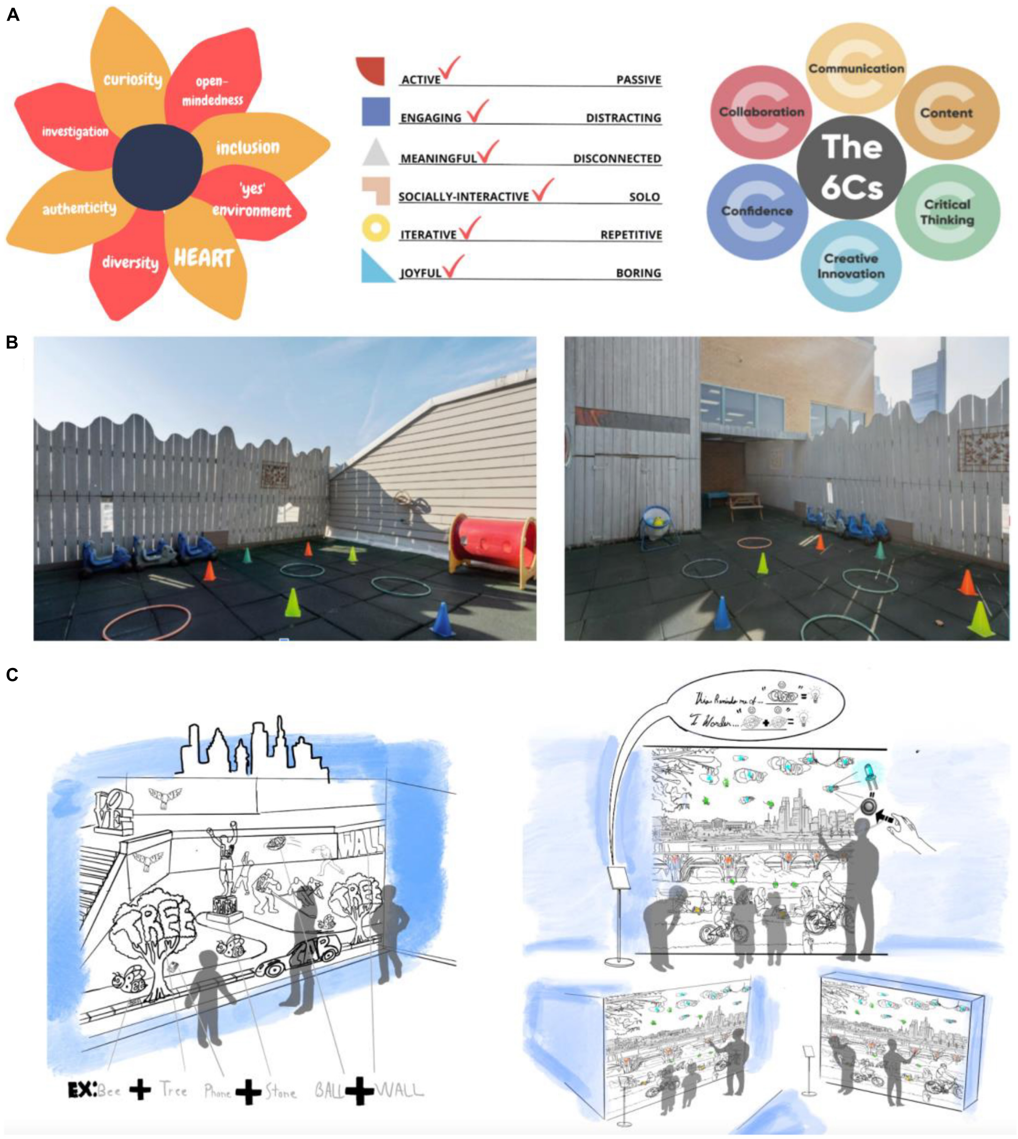

FIGURE 3
Pictured here are images and illustrations representing stages of the co-design process. A represents the guiding principles of the co-design process: **(A)** pinwheel representing the overarching community values identified by participants in the first workshop, a checklist of the pillars of play, and a graphic of the 6 C's. **(B)** shows community-sourced images from one of the centers of their rooftop playground. Teachers expressed that they used to be able to see the city skyline from their playground but can no longer see it during the second workshop. **(C)** shows the designs created by a design team to reimagine what the playground pictured could look like with a playful learning installation. During the third workshop, teachers, directors, and other stakeholders provided feedback on the designs and discussed desired changes and adjustments.

families and teachers were meaningfully engaged in our design workshops. Their sustained engagement speaks volumes to what happens when scientists involve community members in the scientific process.

Evaluating the model

Another strength of our model is that it can be rigorously and reliably evaluated. For example, scientists can design observational and methodological protocols to examine the impact of a PLL on the surrounding community. This part of our process also incorporates the principles of CBPR. Indeed, in Philadelphia, members of the community became part of the scientific team to research the impact of the installations on caregiver–child behavior and child outcomes (Hassinger-Das et al., 2020, 2021). Evaluation of PLLs in previous work reveals that PLL outcomes are measurable and align with our goals of increasing adult–child interaction quality and language use, building positive attitudes and beliefs about playful learning, encouraging ownership of local spaces, and increasing civic engagement (Ridge et al., 2015; Hanner et al., 2019; Bustamante et al., 2020; Hassinger-Das et al., 2020; Gaudreau et al., 2021; Shivaram et al., 2021).

Observations of caregiver–child and teacher–child interactions in our two case studies described in this article will provide additional evidence about the impact PLLs have on interactions and child outcomes. Importantly, in both projects, we are actively taking steps to ensure items in our assessments are culturally appropriate and reflect diverse cultural contexts. For example, the observational protocols being developed to evaluate Case Study 1 are being translated and adapted with community input to reflect the ways in which caregivers express different constructs (e.g., numeric and spatial skills) both behaviorally and linguistically (Melzi et al., 2022). This ensures that our observations capture culture-specific behavior and language relevant to our outcomes of interest.

Previous work has also evaluated caregiver views on play and learning after interacting with PLL. Caregivers with more exposure to PLLs indicated a greater understanding of the connection between play and learning (Grob et al., 2017). A similar approach will be implemented to evaluate play and learning attitudes among Spanish-speaking caregivers who reside in the Case Study 1 community. Surveys will be adapted to specific cultural and community contexts, for example, by engaging in an iterative translation process and soliciting feedback from community members about the relevance of survey items to their culture and community. This process allows us to generate methodological tools that are appropriate to the local community context before administering them in the field.

Child learning outcomes are another measurable outcome of PLL. Recently published work investigated the impact that a PLL called Fraction Ball had on students' fraction and decimal number learning (Bustamante et al., 2022). Fraction Ball is a reimagined basketball court, where lines are added to the court indicating fractions and decimals as a function of distance away from the basket (see **Figure 4**). After modifying courts at an elementary school in Santa Ana, California, fifth and sixth grade students were randomly assigned to play Fraction Ball during their physical education (PE) class period or to engage in PE as usual. Students who played Fraction Ball showed greater improvement in fraction and decimal number understanding from pretest to posttest than students who did not play Fraction Ball and continued business as usual (Bustamante et al., 2022). Drawing from this approach, we plan to examine the impact that PLLs installed in diverse community spaces (Case Study 1) and early learning settings (Case Study 2) have on children's learning. Our team will use data from the Early Development Index (EDI), a teacher-reported population-based assessment of school readiness that evaluates child development in physical health, social competence, emotional maturity, language and cognitive development, and communication to examine whether population-level changes in school readiness emerge in the years following PLL installation in our Case Study 1 community. This will have important implications for urban design and city planning in the long term.

Finally, the impact of PLL on community wellbeing can be evaluated. During our co-design process, community members were given opportunities to meet others who live in their community and to engage with stakeholders, such as funders, policymakers, and researchers. We expect this process to foster civic engagement and increase social cohesion, which can strengthen economic health and wellbeing, particularly in underserved neighborhoods (Hadani et al., 2021). In collaboration with our policy partners at the Brookings Institution, a new metrics framework provides policy-relevant recommendations for measuring these types of community-level outcomes (Hadani et al., 2021). Specifically, data on the frequency of visits to a PLL site, length of visit, community engagement in volunteer activities at the site, small business impact, and accessibility of the site for people with special needs will be acquired to provide additional documentation about how PLLs impact communities. This information will be leveraged to inform and scale our PLL work in future.

Discussion

In this paper, we offer a new model a new model for conducting developmental and educational research that integrates community input and values with the science of *how* and *what* children learn. This is an evidence-based approach that deviates from traditional developmental science research by actively including communities in research design and implementation from the outset. Implementation and evaluation of this model suggest that it not only changes human behavior in public and educational spaces but can do so in culturally sensitive and inclusive ways that are also supportive of high-quality adult–child interactions and child outcomes. In each of our case studies, RPPs were established with trusted community sources, which allowed our research team to develop relationships with local community members, such as parents and educators. This was essential to ensure participation in design sessions, where community input on important values, practices, and design ideas was solicited. Community funds of knowledge were then aligned with evidence-based research from the science of learning about how children learn best and what skills support strong learning outcomes through an iterative process. This yielded installations that reflected the priorities of both the community and scientific practice.

In addition to successfully implementing the model, we showed how this method can be empirically validated in culturally responsive ways. This involves not only designing with communities but also turning to communities as a source of information regarding what is culturally relevant

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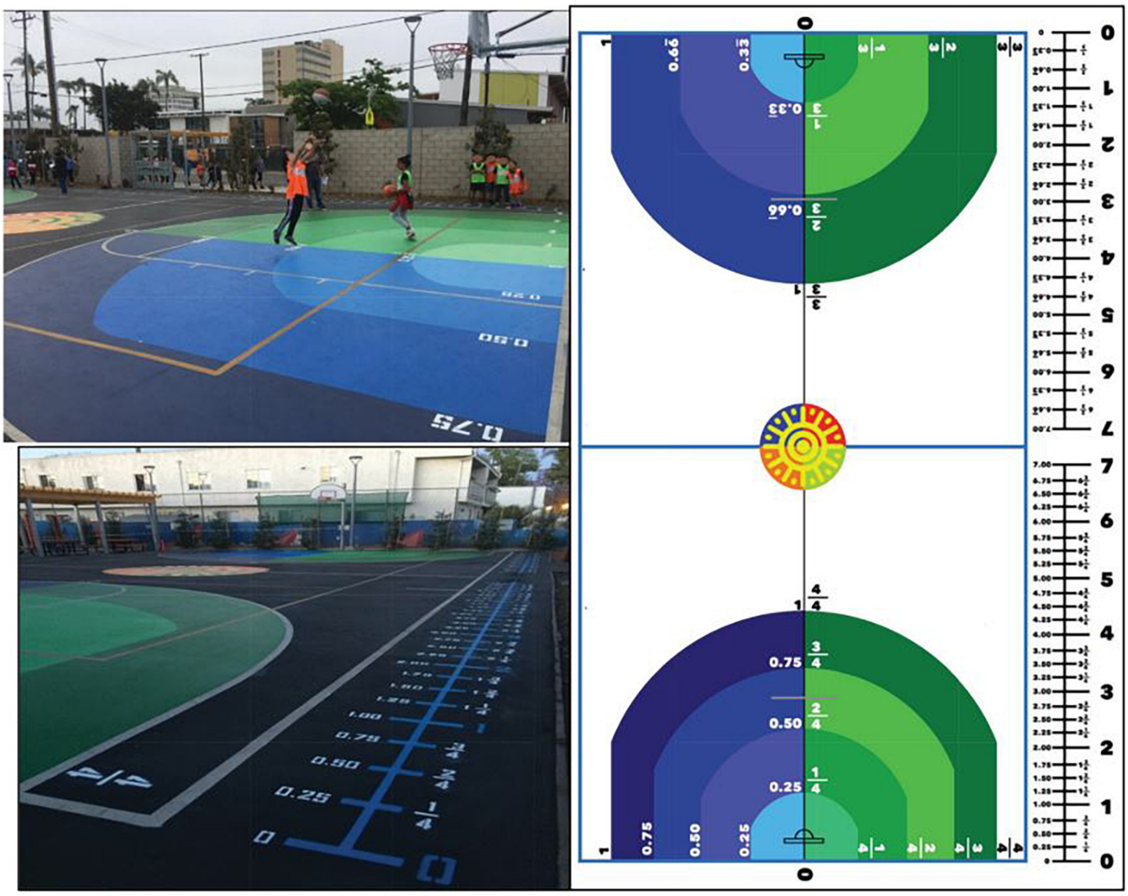

FIGURE 4
Fraction Ball installation in Santa Ana, CA from Bustamante et al. (2022).

and appropriate to measure. Observational protocols and other methodological tools, developed with community input, have been used to evaluate the impact of PLL on families, children, and communities in past PLL projects. We anticipate these measures will reveal the impact that PLLs designed in Case Studies 1 and 2 have on child-learning outcomes, as well as community-wide attitudes and beliefs in the value of playful learning.

This model for conducting psychological research responds to calls from the scientific community to engage in translational research and advance scholarship that fosters a more diverse equitable and inclusive science (Gruber et al., 2019; Rodriguez Espinosa and Verney, 2020; Buchanan et al., 2021; Haden et al., 2022). Translational research offers opportunities not only to apply laboratory-based findings to real-world applications but also to learn about development in real-world contexts (Golinkoff et al., 2017; Thompson, 2019). By inviting community members, including families, government officials, and educators, to take part in our scientific endeavors as research partners and design collaborators, we create space to learn and advance our science together. Communities are afforded opportunities to learn about developmental research from developmental and educational researchers, which opens lines of communication to translate science to families and policymakers. Likewise, researchers have opportunities to garner rich information about family values and dynamics, educational practices, and child development directly from communities in non-experimental settings and with non-traditional methodological approaches. For example, our co-design process in Santa Ana not only aided in the development of designs that reflected the community's cultural values but also it provided our research team with descriptive data about family practices and assets that Latine families use to engage children in STEM learning (Bermudez et al., under review)[1]. In addition, by including families as data ambassadors in PLL projects, we further invite collaboration from diverse populations to inform research questions and design. This allows for a more inclusive science that can better engage with and reflect diverse

1 Bermudez, V. N., Salazar, J., Garcia, L., Ochoa, K. D., Pesch, A., Roldan, W., et al. (under review). *Designing culturally situated playful environments for early STEM learning in a Latine Community*.

populations by engaging them in new ways throughout the research process. Indeed, this type of community-based science asks researchers to consider whose voices are being centered in an initiative and develop scientific practices and methodologies that reflect this. The PLL initiative aims to respond to these calls by integrating community-based participatory research principles with scientific rigor.

Limitations

Though the PLL model is a promising addition to the developmental and educational psychology literature, the Case Studies described in this manuscript are part of an initiative that is still relatively new. Additional implementation and research of the model are needed across a wider range of community contexts, such as additional non-dominant cultural communities and in a wider range of school types, to determine its effectiveness, identify aspects of our model that could use refinement or improvement, and foster opportunities to build connections with more community stakeholders. Indeed, past research has found that community involvement using a culturally responsive approach to co-design engenders increased the sense of ownership of PLLs (Bustamante et al., 2019; Belgrave et al., 2022). Developing a sense of ownership surrounding PLLs can lead to increased use of local spaces, which in turn increases the sustainability of PLL installations long-term and creates models for future PLL installations in other communities looking to adopt this approach. Existing research thus points to the effectiveness of our approach to uphold and reflect community values. However, more work is needed to definitively establish direct PLL impacts on child learning outcomes and overall community wellbeing and civic engagement.

Furthermore, the scope of impact of this work will be made clearer with ongoing efforts to scale PLL through policy innovations and partnerships. While PLL has been successfully implemented in several projects over the past few years (e.g., as described by Bustamante et al., 2020; Hassinger-Das et al., 2020, and in this manuscript), the process for scaling this initiative is in progress. There is evidence supportive of the scalability of both community-based RPP research and playful learning innovations. Research conducted in New Hampshire (Hirsh-Pasek et al., 2022; Nesbitt et al., under review[2]) suggests that the PLL model enacted through facilitated conversations with educators and school leadership can be implemented at the school district level and among populations of older children. In addition, international efforts to implement playful learning models, such as those in Finland, Singapore, India, Canada, and China (Gibbs et al., 2022) point to the widespread adoption of the principles described here that can have global significance and be applied across a wide range of cultural contexts. Coupling the community-based RPP approach with playful learning innovations at scale has the potential to fundamentally reshape how we approach educational priorities and urban development. The generalizability of our model to new cultures and contexts and the integration of this initiative across different sectors (e.g., public policy, education, and government) will advance our understanding of how to successfully conduct translational research that is inclusive and equitable.

Conclusion

With a foundation built upon research with consensus from the scientific community, we further show that scientific theory and application can be built upon areas of agreement, rather than gaps. That is, scientists often conduct research that aims to provide answers to missing questions or to illuminate what we do not yet know about a particular psychological phenomenon. While this is an important lever for advancing scientific inquiry, we offer a complementary approach that asks not only what we do not know but also what we do know and how we can build on past successes for a more successful future. Areas in which relative consensus exists can be used to inform practical applications of research and methods for scaling those applications to the broader community level. PLL is one such example, taking what we know from the science of learning and implementing it into practice to impact how adults and children interact and learn in everyday spaces.

The PLL initiative sits at the nexus of the built and social environments. The unique process of community co-design integrates physical settings with learning goals that align with social customs, practices, and values. By bringing research from laboratories to community spaces, the science of learning can be infused into the everyday places of children's lives. The PLL model thereby offers an opportunity to bridge gaps between research and practice in a human-centered culturally relevant way. As the initiative expands, we will be able to evaluate in greater detail how different moderators (e.g., demographic composition of communities) impact various outcomes (e.g., learning gains and changes in community beliefs). Applying the model described in this manuscript to the development of playful learning cities nationally and internationally has the potential to yield a future generation of leaders with the skills and dispositions needed for global cooperation and success.

2 Nesbitt, K. T., Blinkoff, E., Gunersel, A. B., and Hirsh-Pasek, K. (under review). Play-based learning in New Hampshire kindergarten classrooms.

Ethics statement

The studies involving human participants were reviewed and approved by Human Research Protections (HRP), University of California, Irvine, Irvine, CA and Institutional Review Board (IRB), Temple University, Philadelphia, PA. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

AP, KO, VB, JS, JA, AB, and KH-P contributed to case study 1. AP, KF, RT, HG, and KH-P contributed to case study 2. AP wrote the first draft of the manuscript. KO, KF, VB, RT, and JS wrote sections of the manuscript. HG, JA, AB, and KH-P provided critical revisions to the manuscript. All authors contributed to the case study design and implementation and contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Brett Miller,
National Institutes of Health (NIH),
United States

REVIEWED BY
Sonia Beatriz Echeverria- Castro,
Instituto Tecnológico de Sonora
(ITSON), Mexico
Deborah Schneider,
University of Connecticut,
United States

*CORRESPONDENCE
Paige B. Greenwood
Paige.greenwood@nyspi.columbia.edu

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Effects of prenatal polycyclic aromatic hydrocarbons and childhood material hardship on reading achievement in school-age children: A preliminary study

Paige B. Greenwood[1,2]*, Jacob W. Cohen[2], Ran Liu[1,2], Lori Hoepner[3], Virginia Rauh[4], Julie Herbstman[5], David Pagliaccio[2] and Amy E. Margolis[1,2]

[1]Department of Psychiatry, Vagelos College of Physicians and Surgeons, Columbia University, New York, NY, United States, [2]Division of Child and Adolescent Psychiatry, New York State Psychiatric Institute, New York, NY, United States, [3]Department of Environmental and Occupational Health Sciences, SUNY Downstate Health Science University, Brooklyn, NY, United States, [4]Heilbrunn Department of Population and Family Health, Mailman School of Public Health, Columbia University, New York, NY, United States, [5]Department of Environmental Health Sciences and Columbia Center for Children's Environmental Health, Mailman School of Public Health, Columbia University, New York, NY, United States

Background: Children from socioeconomically disadvantaged backgrounds are at elevated risk for reading problems. They are also likely to live in neighborhoods with high levels of air pollution and to experience material hardship. Despite these risk factors, the links between prenatal chemical exposures, socioeconomic adversities, and reading problems in youth from disadvantaged backgrounds remain understudied. Here we examine associations between prenatal exposure to polycyclic aromatic hydrocarbons (PAH), a common air pollutant, and reading skills, and determine if this relationship is exacerbated by material hardship among Black and/or Latinx children who have been followed as part of a longitudinal urban birth cohort.

Methods: Mothers and their children, who were participants in a prospective birth cohort followed by the Columbia Center for Children's Environmental Health, were recruited for the current study. Personal prenatal PAH exposure was measured during the third-trimester of pregnancy using a personal air monitoring backpack. Mothers reported their level of material hardship when their child was age 5 and children completed measures of pseudoword and word reading [Woodcock Johnson III Tests of Achievement (WJ-III) Basic Reading Index] at age 7. We used multiple linear regression to examine the effects of the interaction between prenatal PAH and material hardship on Basic Reading Index, controlling for ethnicity/race, sex, birthweight, presence of a smoker in the home (prenatal), and maternal education (prenatal) ($N = 53$).

Results: A prenatal PAH × material hardship interaction significantly associated with WJ-III Basic Reading Index scores at age 7 ($\beta = -0.347$, $t(44) = -2.197$, $p = 0.033$). Exploratory analyses suggested that this effect was driven by untimed pseudoword decoding (WJ-III Word Attack: $\beta = -0.391$, $t(44) = -2.550$, $p = 0.014$).

Conclusion: Environmental chemical exposures can be particularly toxic during the prenatal period when the fetal brain undergoes rapid development, making it uniquely vulnerable to chemical perturbations. These data highlight the interactive effects of environmental neurotoxicants and unmet basic needs on children's acquisition of reading skill, specifically phonemic processing. Such findings identify potentially modifiable environmental risk factors implicated in reading problems in children from economically disadvantaged backgrounds.

KEYWORDS

reading, material hardship, air pollution, child development, toxicants

Introduction

Reading disorders (RD) affect 5–11% of school-age children, entailing impairment in single-word decoding, fluency, and reading comprehension (Shaywitz and Shaywitz, 2005; Snowling and Melby-Lervag, 2016). Genetics explain roughly 60% of the variance in RD among children living in socioeconomically advantaged settings, but this does not extend to children living in the context of economic disadvantage (Hensler et al., 2010; Peterson and Pennington, 2015). For these children, environmental factors appear to explain a larger portion of the variance in reading problems (Peterson and Pennington, 2015; Wodtke and Parbst, 2017). Although many household-level factors impacting reading skill acquisition have been examined, the role of the chemical environment, i.e., exposure to neurotoxicants, has been largely overlooked in research assessing reading problems (Margolis et al., 2020a; Margolis et al., 2021). Further, children living in the context of economic disadvantage are disproportionally at risk for such exposures given differential situating of the sources of toxic chemical exposures near lower income neighborhoods (Evans, 2004; Miranda et al., 2011; Bell and Ebisu, 2012; Hajat et al., 2015; Mikati et al., 2018; Jbaily et al., 2022). Thus, because of differential exposure to both toxic chemical and adverse social exposures, we have theorized that children from economically disadvantaged backgrounds will be at excess risk for developing environmentally associated phenotypes of reading problems.

Polycyclic aromatic hydrocarbons (PAH) are a class of air pollutants with known neurotoxicity that are produced by the incomplete combustion of organic materials such as fossil fuels, tobacco smoke, and burning of oil and coal for heat and/or electricity (Boström et al., 2002; Miller et al., 2004). Although air pollution is ubiquitous (Olden and Poje, 1995; Perera et al., 2002; Breysse et al., 2005), economically disadvantaged minority urban populations live in neighborhoods with relatively higher levels of pollution (Bell and Ebisu, 2012; Mikati et al., 2018; Jbaily et al., 2022), placing them at higher risk for adverse health and developmental outcomes (New York City Department of Health, 1998/1999; Claudio et al., 1999; Perera et al., 2002; Federico and Liu, 2003). In the context of the fetal programming theory (Padmanabhan et al., 2016), insults during the perinatal period such as exposure to air pollution could alter neurodevelopmental processes (Davis et al., 2019; Lertxundi et al., 2019) leading to neurological or psychiatric disorders in adulthood (Grandjean and Landrigan, 2014). Early life exposure to air pollution is associated with higher likelihood of poor performance on tests of math and reading (Grineski et al., 2020; Lu et al., 2021) and needing academic support services (Stingone et al., 2017) in childhood. These prior studies relied on area-level models to estimate exposure to air pollution rather than personalized exposure data or individually measured academic achievement tests. We recently reported that higher personal exposure to prenatal PAH exposure was associated with poorer performance on an individually administered measure of reading achievement in adolescence (Margolis et al., 2021). Here we examine associations between personally measured prenatal PAH and individually assessed reading skills in a different sample of younger children also living in the context of economic disadvantage.

Bronfenbrenner's ecological systems theory argues that a child's development is dependent upon a complex system of relationships that are incorporated into their environment longitudinally (Bronfenbrenner, 1979;

Bronfenbrenner and Ceci, 1994; Bronfenbrenner and Evans, 2000). Proximal processes within the "microsystem" or immediate environment are a driving force for human development (Bronfenbrenner and Morris, 1998; Bronfenbrenner and Evans, 2000). In the context of reading acquisition, the development of knowledge and/or skills needed for reading could vary based on what resources are available in the home literacy environment (Crosnoe et al., 2010; Han and Neuharth-Pritchett, 2015; Burris et al., 2019). Early life stressors associated with living in poverty affect cognitive outcomes and academic performance for developing children (Yoshikawa et al., 2012). When examining health disparities among economically disadvantaged children, conventional measures of socioeconomic status (SES), such as parental education, household income, and parental occupation, have been used as predictors (Montgomery et al., 1996; Weinick et al., 1998; Flores et al., 1999). However, findings suggest that proximal measures of overall well-being, like material hardship, may be more sensitive predictors of health outcomes for economically disadvantaged children (Luthar and Cushing, 1999; Beverly, 2000; Ouellette et al., 2004). Black and Latinx children are more likely than White children to live in economically disadvantaged contexts and to experience high levels of material hardship in the form of unmet basic needs, such as inadequate housing, educational and nutritional resources (Vishnevetsky et al., 2015), making material hardship a potentially important factor to consider in models of reading skill acquisition.

Individuals are rarely exposed to a single chemical toxicant or social stressor, and individuals living in the context of economic disadvantage often experience multiple exposures. Such multiple exposures likely have combined effects on developmental outcomes *via* shared cognitive, behavioral, and neurobiological pathways (Lewtas, 1994; Weiss, 2000). Specifically, prenatal PAH exposure exacerbated the effects of early life stress on attention and thought problems in late childhood (Pagliaccio et al., 2020), as well as the effects of maternal stress on hippocampal volumes at age 8 (Margolis et al., 2022). Additionally, higher exposure to environmental tobacco smoke and material hardship was associated with cognitive deficits in the first 2 years of life in urban African American and Dominican youth (Rauh et al., 2004). Notably, the compounding effects of prenatal exposure to air pollution and early life stress on academic skill acquisition have not yet been examined.

In this study, we examine the impact of interactions between personally measured prenatal exposure to PAH and unmet basic needs at age 5 on reading skill at age 7. Given prior work, we hypothesized that higher material hardship would moderate the associations between higher exposure to prenatal PAH and poorer reading skill acquisition in Black and Latinx school-age children. In follow-up analyses, we explore how specific components of reading skill (word reading or pseudoword reading) contribute to any significant associations between exposures and performance on these individually administered reading measures.

Materials and methods

Participants

Fifty-three participants from a prospective longitudinal birth cohort followed by the Columbia Center for Children's Environmental Health were included in the current study. These 53 children were old enough to complete the childhood neurocognitive visit and had available WJ-III Basic Reading Index, prenatal PAH, material hardship, and all covariates (see section "Statistical analyses"). The original cohort enrolled pregnant mothers from obstetrics and gynecology clinics at the New York Presbyterian Hospital and Harlem Hospital between 1998 and 2006 (Perera et al., 2006). Women between the ages of 18–35 were enrolled in the study if they did not use tobacco products or illegal drugs, were free of diabetes, hypertension, or known HIV, and pursued prenatal care in the 20th week of pregnancy. A second cohort enrolled the second born children of these women (total $N = 131$); participants in the current study were enrolled from this second sibling cohort. All participants identified as Black and/or Hispanic/Latinx and resided in Washington Heights, Central Harlem, or South Bronx areas of New York City. This study was approved by the Institutional Review Boards of Columbia University and New York State Psychiatric Institute; parents provided consent and children provided assent.

Prenatal polycyclic aromatic hydrocarbons exposure assessment

Mothers wore an air monitoring backpack for 48 continuous hours during the third trimester of pregnancy and placed it beside their bed when they slept. The backpack contained a filter that collected airborne vapors, aerosols, and particulate matter < 2.5 micrometers (PM2.5) from which eight PAHs (benz[*a*]anthracene, benzo[*a*]pyrene, chrysene, benzo[*b*]luoranthene, benzo[*k*]luoranthene, indeno-[1,2,3-*cd*]pyrene, disbenz[*a,h*]anthracene, and benzo[*g,h,i*]perylene) were extracted and measured (ng/m^3) at Southwest Research Institute (see **Supplementary Table 1**). The total of all eight PAHs was right skewed so the natural logarithm of the data was calculated to provide normal distribution for better fit to the data as done in prior work (Perera et al., 2003; Perera et al., 2012), see **Supplementary material**. The distribution of ln PAH values were mean = 0.59, SD = 0.72. PAH scores were transformed to standardized z-scores for analysis.

Material hardship

A survey was given to the parent when their child was 5 years old to determine material hardship, i.e., unmet basic needs in the past year (Mayer and Jencks, 1989). This included eight questions about affording food, housing, clothing and health-care; response options for question 1 ranged from "very satisfied" to "very dissatisfied" and for the questions 2–8 were "yes" or "no" responses (see **Table 1**).

The responses were summed and rescaled as 0–1 with higher scores representing higher levels of material hardship. This continuous score was standardized and used as an independent variable and moderator in all analyses. One participant's material hardship scaled score was three standard deviations from the mean (z-score > 3) and was winsorized to the next most extreme non-outlier value.

TABLE 1 Survey questions examining material hardship.

1. Think about where you live, the food you eat, and the things you can afford to do and buy. How do you feel about your overall living condition? Would you say?
a. Very satisfied
b. Somewhat satisfied
c. Neither
d. Very dissatisfied
2. In the last year, has there been a time when you and your family needed food but couldn't afford to buy it?
a. Yes
b. No
3. In the last year, has there been a time when you couldn't afford a place to stay, or when you couldn't pay the rent?
a. Yes
b. No
4. In the last year, has your gas or electricity been turned off because you couldn't afford to pay the bill?
a. Yes
b. No
5. In the last year, have you needed to buy any type of clothing for yourself or your family because you couldn't afford to pay for it?
a. Yes
b. No
6. In the last year, has there been a time when you or a member of your family needed medicine or medical care but didn't get the treatment because you couldn't afford it?
a. Yes
b. No
7. Do you currently receive Medicaid?
a. Yes
b. No
8. Do you currently receive any type of public assistance?
a. Yes
b. No

This table display the survey questions completed by mothers to examine items of material hardship such as living conditions, food, housing, clothing, health-care, and public assistance at age 5. Survey questions were rescaled as 0–1 with higher scores representing higher levels of material hardship.

Reading achievement

Reading skills were assessed during childhood (range 6–8 years old, mean age = 6.83, SD = 0.38) by a trained research assistant and checked for administration and scoring by a certified school psychologist and licensed psychologist. Single word and pseudoword reading were measured using the Woodcock Johnson Tests of Achievement-III (WJ-III) (Woodcock et al., 2000), specifically the Word Attack and Letter Word Identification subtests. The WJ-III Letter Word Identification subtest measures untimed single-word reading and requires the participant to read the words out loud. The WJ-III Word Attack subtest requires the participant to read aloud pseudowords (nonsense words) untimed. The WJ-III Word Attack and Letter Word Identification subtests provide age-adjusted standard scores that comprise the weighted-norm Basic Reading Index, measuring untimed decoding abilities.

Children also completed the Test of Word Reading Efficiency-II (TOWRE-II), Site-Word Efficiency (SWE), and Phonetic Decoding Efficiency (PDE) (Torgesen et al., 2012). TOWRE-II is a timed reading assessment that measures the participant's ability to read a list of words (SWE) and pseudowords (PDE) aloud for 45 s each. The SWE and PDE subtests are age-adjusted standard scores combined as a weighted-norm Word Reading Efficiency Index measuring timed decoding abilities.

Statistical analyses

All statistical analyses were performed in IBM SPSS Statistics version 26. Distributions of key variables were assessed to address assumptions of normality in parametric tests (see **Supplementary Figures 1, 2**). The association between prenatal PAH and material hardship was assessed using Pearson correlation. In primary analyses, multiple linear regressions examined whether interactions between prenatal PAH and moderator material hardship were associated with untimed WJ-III Basic Word Reading Index ($N = 53$). Follow-up analyses examined if any significant results were driven by effects on the Word Attack or Letter Word Identification subtests that comprise the Basic Reading Index. PROCESS macro v4.0 for SPSS (Hayes, 2022) was used to determine the conditional effects of prenatal PAH exposure at values of material hardship on WJ-III reading measures. To test the specificity of material hardship in the primary model, control analyses evaluated the interaction between prenatal PAH and maternal education, an alternate measure of socioeconomic advantage, on reading outcomes. Exploratory analyses examined if the interaction between prenatal PAH and material hardship was associated with TOWRE-Word Reading Efficiency Index, which measures timed reading efficiency.

All models controlled for potentially confounding variables, including ethnicity/race (binary: Black or Latinx/Hispanic), sex, birthweight (grams), presence of smoker in the house (binary: yes or no) at prenatal visit, and maternal highest degree of education (categorical: less than high school to 4+ years of college) at prenatal visit. Control analyses examining the prenatal PAH exposure by maternal education interaction term included material hardship as a covariate. Two birthweight values were identified as outliers (z-score > 3) and were winsorized to the next extreme non-outlier value. Age was not included as covariate in the main analysis because the outcome variables (reading measures) were age-adjusted using standardized norms. A sensitivity analysis included age as a covariate. Johnson–Neyman plots were generated in RStudio v.3.5.1 to visualize values of the moderator for which the slope of the predictor is significant ($p < 0.05$). Complete case analyses of the data are presented. All tests were two-tailed, and significance thresholds were set at $p < 0.05$. All linear regression models were checked for normal distribution of residuals (see Supplementary Figure 3).

Results

Participants

Table 2 presents demographic data for the children included in this study. Fifty-four percent of the children identified as Dominican/Latinx and 46% identified as Black/African-American. Relative to children without complete data, a greater percentage of those included in the study were female. Relative to national norms (mean = 100, SD = 15), children's reading scores were in the average range: WJ-III Basic Reading Scores (mean = 104.11, SD = 13.63); TOWRE Word Reading Efficiency Index scores (mean = 93.06, SD = 14.42). The range of observed values for z-scored material hardship were −1.10, 2.93 and for prenatal PAH were −1.95, 1.95. There were no significant associations between prenatal PAH and material hardship ($r = -0.001$, $p = 0.99$).

Effects of prenatal polycyclic aromatic hydrocarbon and material hardship on reading achievement

The prenatal PAH by material hardship interaction term was significantly associated with lower WJ-III Basic Reading Index ($\beta = -0.347$, $t(44) = -2.197$, $p = 0.033$, Figure 1A and Table 3). Higher prenatal PAH was significantly associated with lower WJ-III Basic Reading Index when material hardship values were elevated (z-score > 0.87, raw > 0.45; Johnson–Neyman plot, Figure 1B). For every 1 point increase in prenatal PAH exposure at high levels of material hardship, there is a 7-point decrease in WJ-II Basic Reading Index (see Supplementary Table 2). Including age as a covariate did not change these results (see Supplementary Table 4).

TABLE 2 Participant demographics.

	Participants with prenatal PAH, material hardship and Basic Reading Index ($n = 53$)	**Participants without prenatal PAH, material hardship and Basic Reading Index ($n = 78$)**	**Group comparisons**
Characteristic	Mean (SD) or *N* (%)	Mean (SD) or *N* (%)	
Ln total PAH (prenatal)	0.59 (0.72)	0.55 (0.93)	$t = -0.1945$, $p = 0.85$
Material hardship at age 5	0.30 (0.17)	0.37 (0.21)	$t = 1.812$, $p = 0.07$
Birthweight (grams)	3322.21 (330.35)	3448.58 (485.20)	$t = 1.51$, $p = 0.13$
Sex (% female)	45 (66.0%)	16 (41.0%)	$\chi^2 = 5.690$, $p = 0.02$*
Smoker in the house (% yes, prenatal)	11 (20.8%)	10 (12.8%)	$\chi^2 = 1.476$, $p = 0.22$
Ethnicity/Race (% Dominican)	32(60.4%)	44 (56.4%)	$\chi^2 = 0.204$, $p = 0.65$
Maternal education (prenatal)			$G^2 = 10.65$, $p = 0.16$
Less than HS	0.0%	3(3.8%)	
Some HS	10(18.9%)	14(17.9%)	
HS diploma	8(15.1%)	19(24.4%)	
GED	2(3.8%)	6(7.7%)	
Some college	18(34.0%)	12(15.4%)	
2 year college degree	9(17.0%)	13(16.7%)	
4 year college degree	4(7.5%)	9(11.5%)	
4+ years of college	2(3.8%)	2(2.6%)	

This table displays demographic data for children included in the current study ($n = 53$) and those not yet old enough to complete the childhood neurocognitive visit ($n = 78$). Ln total PAH, natural logarithm of total polycyclic aromatic hydrocarbon; HS, high school; GED, general educational development; SWE, site-word efficiency; PDE, pseudoword decoding efficiency. *$p < 0.05$.

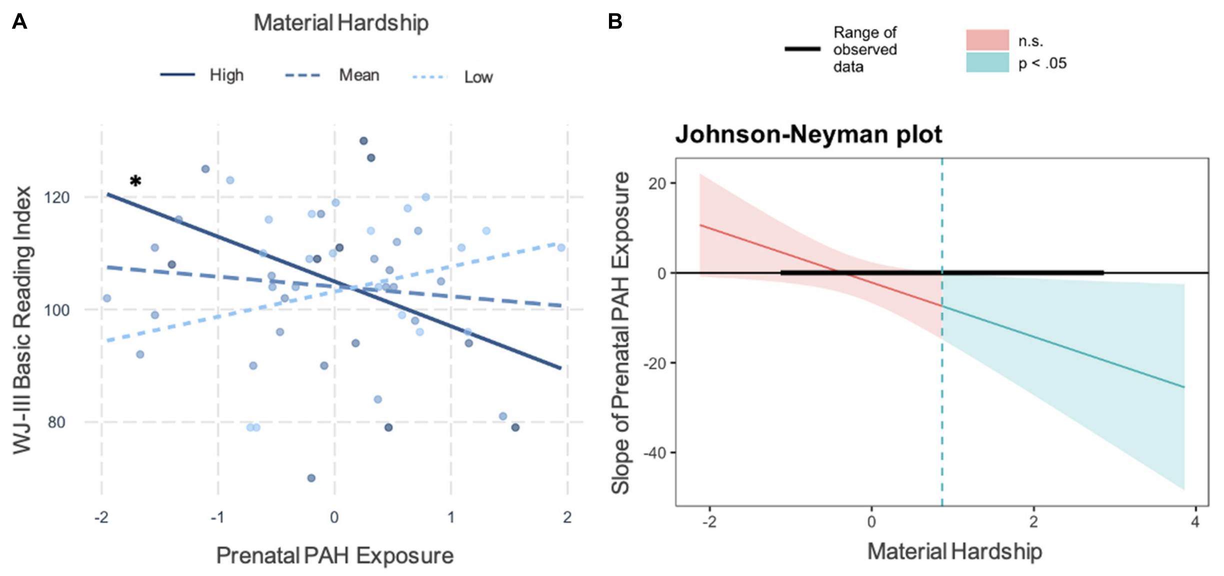

FIGURE 1
Interaction plot showing prenatal PAH by material hardship predicting *WJ-III* Basic Reading Index. **(A)** The prenatal PAH by material hardship interaction associated with lower Basic Reading Index at child age 7. Higher PAH associated with lower Basic Reading Index scores at higher levels of material hardship (mean ± 1SD), $^*p < 0.05$. **(B)** Johnson–Neyman plot showing the slope of the association between prenatal PAH and Basic Reading Index at age 7 (*y*-axis). PAH was z-scored *here* ($M = -0.05$, SD = 0.90) so the slope can be interpreted as a 1 SD increase in PAH is associated with a Y unit change in Basic Reading Index scores. The observed range of material hardship z-scores was −1.10, 2.83 which is noted in black by the bold line at $y = 0$. The region of significance analysis indicates $p < 0.05$ significant association between prenatal PAH and Basic Reading Index in the shaded blue region, (no significant associations in the red, at values of material hardship between −3.18, 0.87). *represents a significant slope.

In follow-up analyses, the prenatal PAH by material hardship interaction was significantly associated with pseudoword decoding (WJ-III Word Attack: β = −0.391, $t(44) = -2.550$, $p = 0.014$, Figure 2A and Supplementary Table 3). Higher prenatal PAH was significantly associated with lower pseudoword decoding when material hardship values were higher (z-score > 0.28, raw > 0.35; Johnson–Neyman plot, Figure 2B). For every 1 point increase in prenatal PAH exposure at high levels of material hardship, there is a 7-point decrease in WJ-II Word Attack scores (see Supplementary Table 5). This association was not significant at lower values of material hardship. In control analyses, the prenatal PAH by maternal education interaction term on Basic Reading Index was not significant (β = 0.723, $t(44) = 1.709$, $p = 0.095$). In an exploratory analysis, the prenatal PAH by material hardship interaction term on the TOWRE Word Reading Efficiency Index was not significant (β = −0.288, $t(40) = -1.697$, $p = 0.097$, $n = 49$).

TABLE 3 Regression analyses predicting WJ-III Basic Reading Index.

N = 53	WJ-III Basic Reading Index		
	β	*t*	*P*
Ethnicity/Race	0.076	0.555	0.582
Maternal education (prenatal)	−0.044	−0.275	0.785
Sex	−0.082	−0.566	0.574
Birth weight (grams)	−0.299	−1.974	0.055
Smoker in the house (prenatal)	−0.015	−0.093	0.926
Ln total PAH (prenatal) – Z-scored	−0.139	−0.961	0.342
Material hardship at age 5 – Z-scored	0.066	0.417	0.679
PAH × Material hardship*	−0.347	−2.197	0.033

WJ-III Basic Reading Index is the dependent variable in the regression analyses. All models control for ethnicity/race, maternal education (prenatal), sex, birthweight (grams), and smoker in the house (prenatal). Regression coefficients (β) and their corresponding t-statistic and *p*-values are presented for all predictors in the model. $^*p < 0.05$. Ln total PAH, natural logarithm of total polycyclic aromatic hydrocarbon.

Discussion

The current study aimed to investigate if interactions between early life chemical and social exposures impact the development of reading outcomes for Black and Latinx children. Prior studies have separately examined the contributions of air pollution (Stingone et al., 2017; Grineski et al., 2020; Lu et al., 2021) and social adversities (Noble et al., 2006a; Dolean et al., 2019) to academic achievement. Here we show for the first time that prenatal exposure to PAH and material hardship have interactive effects on reading skill acquisition, and that such effects appear to be driven by pseudoword reading. Consistent

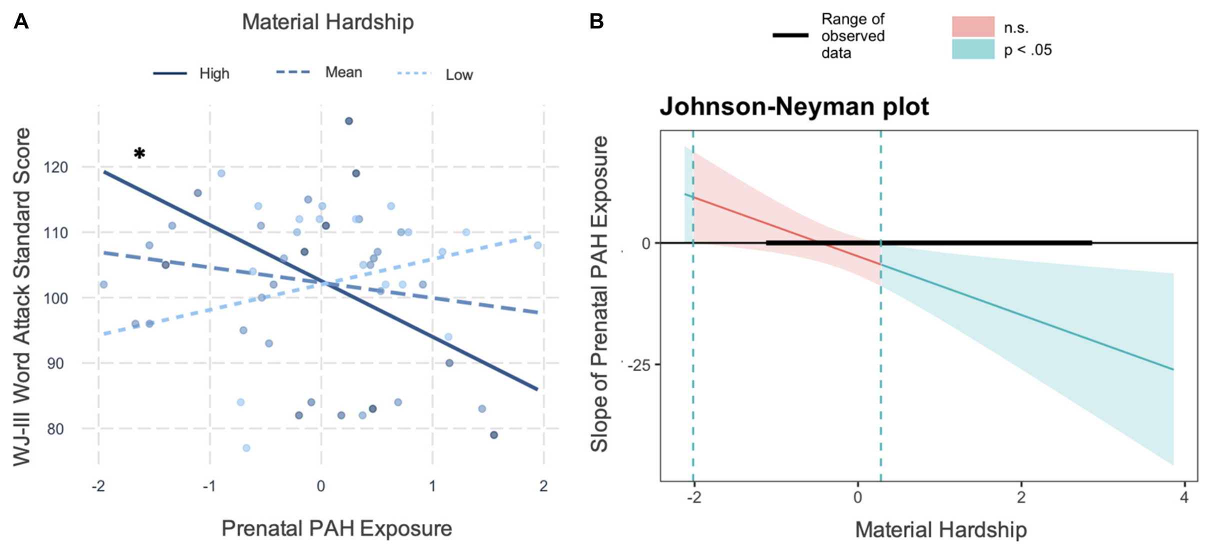

FIGURE 2
Interaction plot showing prenatal PAH by material hardship predicting WJ-III Word Attack standard scores. **(A)** The prenatal PAH by material hardship interaction associated with lower Word Attack standard scores at age 7. Higher PAH associated with lower Word Attack standard scores at higher levels of material hardship (mean ± 1SD), $*p < 0.05$. **(B)** Johnson–Neyman plot showing the slope of the association between prenatal PAH and Word Attack standard scores at age 7 (*y*-axis). PAH was z-scored here ($M = -0.05$, $SD = 0.90$) so that the slope can be interpreted as a 1 SD increase in PAH is associated with an Y unit increase in Word Attack values. The observed range of material hardship values was −1.10, 2.83 which is noted in black by the $y = 0$ line. The region of significance analysis indicates a $p < 0.05$ significant association between prenatal PAH exposure and Word Attack standard scores in the shaded blue region, (no significant associations in the red, at values of material hardship between −2.02, 0.28). *represents a significant slope.

with prior findings that more proximal versus conventional measures of SES provide greater insight into health disparities, we report that material hardship, and not maternal education, interacts with prenatal PAH to affect children's reading skills. Critically, identifying material hardship as a moderator of children's acquisition of reading skill provides a specific and modifiable target for prevention and intervention.

High exposure to both PAH and material hardship were associated with lower word reading scores. Word reading relies on decoding abilities through knowledge of grapheme-phoneme correspondence (Simos et al., 2002). The process of decoding words is supported by executive functions such as inhibitory control (Margolis et al., 2020b) which allows individuals to suppress prepotent responses and avoid guessing an orthographically similar word based on incomplete phonological information (Seidenberg et al., 1984; Messer et al., 2016). Childhood inhibitory control is vulnerable to the effects of environmental air pollution (Chiu et al., 2016; Margolis et al., 2016; Guxens et al., 2018) as well as poverty (Raver et al., 2013; Lawson et al., 2018). Thus, the compounding effects of prenatal air pollution exposure and unmet basic needs could impact the ability to reject irrelevant stimuli during word reading, resulting in poorer word recognition. Such findings are consistent with our prior work showing childhood inhibitory control as a mediator of pollution-related effects on adolescent reading comprehension (Margolis et al., 2021). Since reductions in word reading automaticity may underlie cognitive interference that disrupts reading comprehension (Lyon et al., 2003), pollution-related effects on emerging word reading skills observed in young children could develop into an adolescent phenotype characterized by difficulty with comprehension.

Alternatively, word reading problems might derive from deficits in automaticity and fluency rather than from decoding problems (Wolf and Bowers, 1999), as proposed in the double deficit hypothesis of reading. In this model, rapid automatized naming (RAN) underlies word reading accuracy and early reading fluency (Norton and Wolf, 2012; Araújo et al., 2015). Such processes are thought to rely on processing speed (Georgiou et al., 2013), which is a target of exposure to air pollution (Peterson et al., 2015) and poverty (Zeki Al Hazzouri et al., 2017). Thus, the observed effects of exposure on word reading could derive from the combined effects of exposure to air pollution and material hardship on processing speed, ultimately influencing word reading. Future studies should examine processing speed and inhibitory control as potential cognitive mediators of this environmentally associated phenotype of reading problems. In support of this hypothesis, the neural correlates that underlie these proposed cognitive mediators have been shown to be vulnerable to both air pollution exposure (Peterson et al., 2015; Guxens et al., 2018) and social adversities (Kishiyama et al., 2009; Zheng et al., 2022).

The combined effect of prenatal PAH exposure and childhood material hardship on word reading was driven by performance on pseudoword decoding. When reading pseudowords, a child is required to use knowledge of grapheme to phoneme conversion to serially decode unfamiliar non-words (Ouellette and Beers, 2008). The combined effects of environmental air pollution and unmet basic needs may impact phonological decoding *via* alterations to the left-lateralized reading circuit (Richlan et al., 2009; Richlan, 2012) or to circuits distinct from those typically identified in poor readers from higher SES backgrounds (Noble et al., 2006b). Both word and pseudoword reading engage the left occipital fusiform cortex (Devlin et al., 2006) which stores abstract visual word forms (Price, 2000). Activation in this region during a reading-related task was sensitive to sociodemographic factors such that brain-behavior associations were attenuated in children from higher but not lower SES backgrounds (Noble et al., 2006b). Specifically, despite poor phonological ability, children from lower SES backgrounds engaged regions involved in visual word recognition whereas children from higher SES did not. Such findings support our premise that an environmentally associated phenotype of reading problems may derive from effects of exposure on brain circuits not typically identified in children from higher SES backgrounds who have reading problems. Future studies should examine the impact of these exposures on brain functioning during reading-related tasks.

Black and Latinx children disproportionately live in economically disadvantaged contexts that include lower income neighborhoods with greater concentrations of air pollution (Bell and Ebisu, 2012; Mikati et al., 2018; Jbaily et al., 2022). The distribution of total PAH in our sample was similar to observed levels of toxicity in prior work showing that participants with higher exposure to prenatal PAH (relative to the rest of the sample) moderated the associations between maternal perceived stress and hippocampal volume (Margolis et al., 2022) and was associated with worse reading comprehension (Margolis et al., 2021). Minoritized children living in socioeconomically disadvantaged contexts are also more likely to experience material hardship in the form of housing, health, and food insecurities (Vishnevetsky et al., 2015). Here we examined unmet basic needs at age 5, which is a developmental time point when children are building the foundation for word reading through exposure to books and shared reading with their parent/caregiver (Puglisi et al., 2017). Thus, higher levels of material hardship in the early years may represent a pathway through which children are unable to develop these foundational reading competencies. Further, higher material hardship could increase parental distress and depression (Ashiabi and O'Neal, 2007; Gershoff et al., 2007; Zaslow et al., 2009), and affect positive parenting practices such as attending museums or providing access to books (Gershoff et al., 2007; Zaslow et al., 2009). Such pathways to academic disparities have important public health implications and identify potentially modifiable targets for supporting the overall well-being and academic achievement of Black and Latinx children.

Our study has some limitations. Given the sample size, these findings should be viewed as preliminary. Future studies with larger samples and longitudinal measurement of postnatal PAH exposure may improve our understanding of these trajectories. Our data do suggest that children living in economic disadvantage may be at increased risk for environmentally associated phenotypes of reading problems. We controlled for confounding variables such as ethnicity/race, sex, birthweight, presence of smoker in the house, and maternal years of education at prenatal visit; however, we may not be accounting for other variables that contribute to word reading variability such as the nature of parent-child reading interactions (Demir et al., 2011) or classroom instruction (Cameron et al., 2008). Our dataset does not include a school quality variable; this important variable should be considered and collected in future studies. In addition, our dataset comes from a sample of women and children from economically and racially disadvantaged backgrounds, where high levels of toxic environmental exposures further contribute to learning problems in these populations.

In conclusion, our findings suggest that children exposed to neurotoxicants such as air pollution and material hardship could manifest word reading problems by school-age. This environmentally associated phenotype of reading problems may represent the beginning of a negative cascade of events ultimately leading to altered reading comprehension skills in adolescence, as we have shown in prior work (Margolis et al., 2021). Structural factors that marginalize people of color into living in lower income neighborhoods with higher levels of toxic chemical exposures suggest a specific pathway by which academic disparities in children of color may arise, and some of these conditions are difficult to address, requiring a commitment to geopolitical change. The National Center for Education Statistics shows that economically disadvantaged children lag behind their peers on tests of reading achievement at 4th and 8th grade, calling attention to a steady achievement gap (NCES, 2020). Herein, our findings highlight the need to include a longitudinal assessment of reading outcomes to identify modifiable targets for intervention and potential prevention of environmentally associated phenotypes of reading problems. These data also show a need for scientific evidence to be incorporated into public policy to create sustainable change and address environmental health disparities that greatly impact child development. Critically, we note that legislation to reduce air pollution in New York City has led to declines in exposure which could translate to reductions in health risks (Lovasi et al., 2022). In the immediate future, our work may drive public health regulatory activity with an important impact on the reduction of these neurotoxic environmental exposures that contribute to the pathway, thereby protecting disadvantaged children from further harm. In addition, raising awareness in economically disadvantaged communities about the harmful effects of environmental pollutants could spark scientific and community centered partnerships to fight these growing disparities.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the Institutional Review Boards of Columbia University and New York State Psychiatric Institute. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

PG, JC, DP, RL, and AM performed the statistical analyses and data interpretation. AM, JH, VR, and LH performed the data collection with the Columbia Center for Children's Environmental Health. All authors wrote, reviewed, edited, and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.933177/full#supplementary-material

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EDITED BY
Parisa Parsafar,
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Joshua Levy,
Dartmouth Hitchcock Medical Center, United States
Edward M. Sosu,
University of Strathclyde, United Kingdom

*CORRESPONDENCE
Elizabeth H. Connors
✉ elizabeth.connors@yale.edu

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Structural school characteristics and neighborhood risk factors: Associations with student-reported school climate in a large, urban public school district in the United States

Stephanie A. Moore[1], Rachel R. Ouellette[2] and Elizabeth H. Connors[2]*

[1]School of Education, University of California, Riverside, Riverside, CA, United States, [2]Department of Psychiatry, School of Medicine, Yale University, New Haven, CT, United States

Introduction: School climate consistently predicts youth academic success, social–emotional well-being, and substance use, and positive school climate can buffer the negative effects of community violence exposure on youth development. Various structural school and neighborhood factors have been associated with school climate, but prior research has not examined these relations comprehensively.

Methods: We examined the relation between 18 school building and school neighborhood factors with student-reported school climate among 15,833 students in 124 public schools in a large, urban district in the United States.

Results: In this sample, attendance rate was most consistently associated with school climate ($\beta=0.015$; $p<0.001$). Teacher years of experience, mobility rate, number of students in special education, adult arrests in the school neighborhood, and service calls for shootings and dirty streets and alleys in the school neighborhood were also significantly associated with various domains of school climate.

Conclusions: These findings highlight the need for future longitudinal research on the influence of both school building and school neighborhood factors on school climate for public schools. Schools in our sample had a wide range of school climate scores despite consistently high crime rates and other structural risk factors such as low socioeconomic status throughout the city, so there are implications for researchers and education leaders to work together to identify opportunities for schools to foster positive school climate despite systemic school and/or neighborhood risk factors.

KEYWORDS

school climate, school attendance, student mobility, neighborhood safety, socioeconomic factors in education

1. Introduction

There is growing emphasis in education, children's behavioral health, public health, and public policy on promoting safe and supportive schools to optimize student well-being, resilience, and success (National Center for Safe and Supportive Schools, 2020; U.S. Department of Education, 2022a, b). Simultaneously, there is an enduring understanding of the effects of neighborhood characteristics and concentrated disadvantage on child and adolescent well-being and academic outcomes (Leventhal and Brooks-Gunn, 2000; Sampson et al., 2008) and an increasing nationwide concern about community safety and the impact of neighborhood risk, such as exposure to neighborhood violence and adverse events, on students and their school experience (e.g., Burdick-Will, 2018; Ruiz et al., 2018). Positive school climate is one protective factor that can buffer the negative effects of community violence exposure on students' later development of trauma symptoms and academic underachievement (Ozer et al., 2010; O'Donnell et al., 2011). School climate consistently predicts numerous youth outcomes, including academic success (e.g., Kwong and Davis, 2015), social–emotional well-being (e.g., Ruus et al., 2007), and substance use (e.g., Gase et al., 2017). Various school and neighborhood factors have been associated with school climate (e.g., O'Donnell et al., 2011; Starkey et al., 2019), but prior research has not examined these relations within the same analytic models to compare strength of effects in predicting school climate in a local school system context. It remains unclear which factors are most strongly related to school climate and may be the most impactful levers for effecting change. There is a pressing need to better understand community- and school-level predictors of school climate, particularly in communities with high crime rates and other structural factors such as low socioeconomic status that confer higher risk to individuals.

Before we can begin to predict school climate, we first need to understand how to measure it. School climate is a multidimensional construct reflected in numerous theoretical frameworks and measurement tools (e.g., Thapa et al., 2013; Wang and Degol, 2016). Common school climate dimensions include: (1) *Academic,* including a positive and effective learning environment; (2) *Community,* including healthy and supportive relationships across and between students, teachers, and other school staff; (3) *Safety,* including both physical and social–emotional safety; and (4) *Institutional Environment,* including perceptions of organizational resources and environmental features of the school (Wang and Degol, 2016). Student-reported school climate focuses on students' subjective experience of their school's "norms, goals, values, interpersonal relationships, teaching and learning practices, and organizational structures," as, "socially, emotionally and physically safe" (National School Climate Council, 2007, pp. 4–5). Validated measures of school climate exist (e.g., U.S. Department of Education School Climate Surveys, American Institutes of Research, 2022), however a wide array of measures are used in practice by schools and in research (Grazia and Molinari, 2021). Definitions of school climate and measured constructs vary considerably among existing tools (Thapa et al., 2013).

While school climate focuses on students' subjective experiences at school, this differs from structural school building factors, such as student-teacher ratios, level of teacher experience, enrollment, and student mobility. Johnson et al. (2017) highlight the importance of examining both structural school-level factors (e.g., observed features of school physical and social environment) and student perceptions of school climate, as school environment changes were only associated with decreased student violence if there were corresponding changes in students' perceptions of their school. School factors include tangible aspects of the school environment while school climate is based on students' subjective experiences, so examining school factors as predictors of school climate enables researchers and school districts to identify objectively-measured aspects of the school environment that could be malleable to change to improve school climate. There are many facets that construct and influence a school's physical, social, emotional, and academic environment. Different school structural factors, including class size and faculty turnover, have been associated with specific domains of school climate, including perceptions of order and discipline as well as academic motivation (Koth et al., 2008; Bradshaw et al., 2009; O'Donnell et al., 2011; Steinberg et al., 2015; Starkey et al., 2019). One study of 1,881 fifth-graders found that student mobility, student-teacher ratio, faculty turnover and principal change were significantly related to student-reported school climate (Bradshaw et al., 2009). Most studies examine predictors of overall school climate, however specific subdomains of school climate (e.g., supportive relationships; Hopson et al., 2014) are particularly strong predictors of student outcomes (e.g., positive behaviors and academic success), highlighting the importance of identifying predictors of specific school climate domains. Indeed, there are a small handful of studies examining school building and school neighborhood factors as predictors of school climate, and the results are mixed. Much still needs to be understood about the association between specific school factors with different school climate dimensions to identify the most impactful levers for change at the school and school neighborhood level towards improving different facets of school climate.

In terms of how neighborhood and community contexts surrounding schools influence perceived climate on school grounds, a long history of research demonstrates significant associations between student experiences in the neighborhood and at school, but these relations are complex and somewhat inconsistent. For example, multiple studies identify positive associations between neighborhood violence and school violence (Laub and Lauritsen, 1998; Siller et al., 2021), as well as between students' perceived neighborhood safety and perceived school safety (Hong and Eamon, 2012). However, Limbos and Casteel (2008) found no statistically significant association between neighborhood and school crime among a sample of 95 Los Angeles middle and high schools, but identified neighborhood dilapidation as positively and significantly associated with school crime after controlling for neighborhood crime. Foster and Brooks-Gunn (2013) also identified residential instability as a significant and positive predictor of school victimization. These results highlight how multiple neighborhood factors, including crime rates, concentrated poverty, housing instability, and ineffective infrastructure can influence students' school experiences, but that these trends vary depending on the neighborhood factor and locale.

While there is substantial research connecting neighborhood-level risk factors with negative school outcomes, such as school crime and victimization, there is limited literature connecting neighborhood factors with the positive dimensions of school climate (e.g., perceived safety). Neighborhood factors and school climate have been separately demonstrated as significant predictors of student outcomes, including academic success and social–emotional well-being (Chetty and Hendren, 2015; Wang and Degol, 2016). When entered into the same analytic models, school climate is frequently identified as a significant moderator and/or mediator of the negative association between neighborhood-level risk factors (e.g., community violence) and student outcomes, including externalizing behaviors (Gaias et al., 2019), post-traumatic stress (O'Donnell et al., 2011) social–emotional development (Starkey et al., 2019), test scores (Laurito et al., 2019), and academic achievement (Hopson and Lee, 2011; McCoy et al., 2013). However, these associations are not consistent (Hardaway et al., 2012; Coker, 2016) and differ across dimensions of school climate (Starkey et al., 2019) and levels of community violence exposure (O'Donnell et al., 2011). This calls for a more nuanced understanding about the relation between neighborhood factors and specific subdomains of school climate.

Studies have also highlighted the collective impacts of school and neighborhood factors on student outcomes. For example, Kirk (2009) found that school collective efficacy helped compensate for the absence of neighborhood collective efficacy in predicting school suspension, and youth experiencing a lack of both neighborhood and school collective efficacy were most at risk for future arrest. This emphasizes the importance of examining the effects of school building factors (i.e., inside the schoolhouse) and school neighborhood factors (i.e., surrounding the schoolhouse). This area of inquiry is supported by the more recent Systems View of School Climate which is a theoretical framework situating school climate within the broader ecological systems of the school, family, community, social and educational systems (Rudasill et al., 2018). While both school and neighborhood factors are frequently associated with school climate in the literature, these associations vary across studies, with different school and neighborhood factors identified as the most salient predictors of school climate depending on the study and subdomain of school climate that is entered into the model. These variations in study findings may be due to differences in contextual factors that influence which school and neighborhood factors are most significant in impacting students' school experiences as well as variation in how school climate is measured across school districts. This makes it difficult to apply previous empirical findings to inform local change efforts within schools who want to create a more positive climate.

Our study presents an analytic strategy for examining local school and neighborhood data in a large, urban district with some of the highest crime rates in the nation to identify the most salient school- and neighborhood-level predictors of school climate in that context. Within this study, we: (1) analyze the factor structure of a local school climate measure; (2) examine unique associations of theoretically-selected school building and school neighborhood predictors of school climate; and (3) examine predictors of overall school climate and climate subdomains to identify similarities and differences in predictors across different aspects of school climate. This analytic approach presents a method for school systems to apply available data from their building and surrounding neighborhood to contribute to a localized understanding of what may be driving student-reported school climate.

2. Materials and methods

2.1. Data sources

This cross-sectional, multilevel study merged secondary data from four different sources indexed at the school and neighborhood level. First, student-reported school climate data were collected by Baltimore City Public Schools district in the spring of 2017 for the 2016–2017 school year as part of an annual school climate survey administered to students, parents, and staff. Use and secure transfer of these data were approved by the Baltimore City Institutional Review Board. School climate data were obtained for 124 schools (see "Sample" and Table 1 for more information on the final sample). There were no exclusion criteria; we used all available 3rd through 5th grade student-reported data. Second, neighborhood predictors were obtained in October 2019 from a public-domain database comprised of numerous data sources from 2016 that is maintained by the Baltimore Neighborhood Indicators Alliance-Jacob France Institute (BNIA-JFI). BNIA-JFI organizes neighborhood data specific to Baltimore city by Community Statistical Area boundaries ($N = 55$), which are based on U.S. Census tracks and are consistent over time (Baltimore Neighborhood Indicators Alliance, 2018). Neighborhood predictors from the BNIA-JFI database that were included in this study were selected based on review of the literature (e.g., Nieuwenhuis and Hooimeijer, 2016; see Supplementary File 1). Third, school-level predictors were selected based on review of the available literature (e.g., Thapa et al., 2013; Wang and Degol, 2016; see Supplementary File 1) and 2016–2017 data were obtained for each school from one of two sources, which were Great Schools (GreatSchools, 2022) and the Maryland School Report Card. GreatSchools is a U.S.-based nonprofit organization that provides information about school quality that is collected from states' departments of education and the U.S. federal government (GreatSchools, 2022). The Maryland School Report Card depicts data collected by schools and districts as part of the state's federally-required educational accountability system

TABLE 1 Descriptive statistics for variables in multilevel models.

Variable	Min	Max	Mean	SD
School building fixed effects (Level 2)				
Student–teacher ratio	3.0	25.0	17.3	2.4
Teacher 3+ Years of experience (%)	45.0	100.0	80.1	12.6
Certified teachers (%)	0.0	22.0	1.7	3.6
Enrollment	39.0	1,366.0	526.6	251.0
Attendance *(<90% = chronically absent)*	86.0	99.4	93.0	2.2
Mobility	1.5	72.7	30.6	14.6
Students with free and reduced meals (%)	10.3	90.5	62.6	18.3
Students in special education (%)	5.2	92.6	10.1	4.2
School neighborhood fixed effects (Level 2)				
Shootings*	0.0	7.0	2.1	1.7
Adult arrests*	0.5	60.0	23.5	16.9
Dirty streets and alleys*	2.2	237.6	64.4	60.1
Clogged storm drains*	1.0	7.9	3.5	1.6
Female-headed households with children (%)	9.1	91.8	53.4	20.9
Median household income	$15,468	$109,518	$44,934	$20,563
Narcotics calls*	0.7	219.5	57.5	58.2
Violent crime*	1.8	40.7	18.5	9.1
Residential properties vacant/abandoned (%)	0.0	33.5	8.6	10.2
Employed adults (%)	43.6	88.1	60.6	10.5
School climate outcomes				
Overall climate	0	1	0.61	0.21
School community	0	1	0.60	0.30
Institutional environment	0	1	0.71	0.28
Sense of safety	0	1	0.76	0.27
Physical safety	0	1	0.33†	0.36

*Per 1,000 residents. †This domain could have been subject to response bias per reverse-worded items. Reverse coding and domain scores have been thoroughly checked to confirm accuracy.

(Every Student Succeeds Act [ESSA], 2015). Data for each Baltimore City Public School included in this study were obtained by a manual search of each organization's online user interface.

Factor analyses on the school climate measure were conducted on the school climate data alone (i.e., the first data source described above). However, the multilevel models, which were the primary analysis for our research questions, were conducted on a merged dataset including all four data sources. Data from each data source were merged based on their nested structure and cleaned using Microsoft Excel and SPSS. First, all neighborhood-level predictor data from BNIA-JFI were merged by community statistical area number. Second, the aggregate school-level predictor data from GreatSchools and the Maryland School Report Card were merged by school number. Schools were then matched to community statistical area by school address lookup on the BNIA website. Fourth, school building and school neighborhood data were merged by community statistical area number that belonged to the school address. Finally, student-level school climate survey data were merged by school number. This resulted in a fully-nested hierarchical model in which students are nested within school buildings nested within school neighborhoods. We hypothesized that both school and neighborhood factors would be associated with student-reported school climate.

2.2. Measures

2.2.1. School climate

Student-reported school climate data were from a survey with 31 school climate items (Supplementary File 1; Supplementary Table S1), scored on a dichotomous zero (*Disagree*) or one (*Agree*) scale, collected by the Baltimore City Public Schools. The internal structure of the school climate measure had not been previously validated. Therefore, the first and senior first author independently reviewed all 31 items for

TABLE 2 Standardized factor loadings for the four-factor CFA model.

Factor	Item	λ
School community	Students respect each other	0.75
	Students respect school staff	0.73
	I feel like I belong at this school	0.76
	School staff respect the students	0.54
	I would choose to stay at my school even if given the option to change schools	0.67
Institutional environment	I have the chance to do music, art, dance, or plays at my school	0.40
	The school building is clean and well maintained	0.66
	This school is well lit	0.41
Sense of safety	If students break rules, there are fair consequences	0.44
	There is someone at my school who I can talk to about my problems	0.43
	I feel safe at my school	0.81
	Students feel safe going to and from school	0.53
Physical safety	Students are NOT often roaming in the halls during class time at this school	0.82
	Students fighting is NOT a problem at this school	0.88
	Students picking on/bullying other students is NOT a problem at this school	0.61

alignment with school climate constructs as operationalized by the ED School Climate Model domains and topics (U.S. Department of Education, 2022a). Following consensus discussions, we removed 11 items for non-relevance (e.g., grit, general satisfaction, academic performance). We then independently reviewed and coded the remaining 20 items as being either representative or not representative of individual school climate constructs (e.g., safety), also as operationalized by the ED School Climate Model domains and topics (U.S. Department of Education, 2022a). Final codes for each item were reached *via* consensus discussions and supported by Wang and Degol's (2016) review of the school climate construct and its measurement. One additional item was removed for non-relevance (i.e., "my teachers can give me extra help with schoolwork when I need it") and the remaining 19 items were coded into three school climate domains: community ($n = 6$), institutional environment ($n = 6$), and safety ($n = 7$).

Given our hypotheses about the internal structure of the school climate measure, we began our internal structure validation process with confirmatory factor analysis or "CFA" (Byrne, 2005). A CFA using weighted least squares with mean and variance adjustment (WLSMV) estimation (Rhemtulla et al., 2012) was conducted with the remaining 19 items loading onto our three theoretically informed domains (i.e., community, institutional environment, safety). However, the CFA yielded poor fit: Comparative Fit Index (CFI) = 0.78, Tucker Lewis Index (TLI) = 0.74, and Root Mean Square Error of Approximation (RMSEA) = 0.076 (90% Confidence Interval [CI] = 0.075, 0.078; Browne and Cudeck, 1989; Hu and Bentler, 1998). We then removed two items with standardized loadings below 0.40 prior to running a second CFA (17 items), but model fit did not improve, and the model modifications indices were theoretically incongruent. Therefore, we conducted an exploratory factor analysis (EFA) using a randomly-selected half of the data to identify potential avenues for model re-specification (Schmitt, 2011). Results of an EFA performed with 17 items for one to six domains supported adding a fourth domain, comprised of three "safety" items that were each reverse coded and measured aspects of Physical Safety (e.g., "Students fighting is a problem at this school"), and removal of two additional items (i.e., one that loaded poorly across domains and another that had poor response variability). A final CFA specifying four domains—School Community, Institutional Environment, Sense of Safety, and Physical Safety—on the 15 remaining items and using the second half of the data resulted in acceptable fit: CFI = 0.92, TLI = 0.90, RMSEA = 0.057 (CI = 0.056, 0.059). The final item loadings are included in Table 2.

The factor solution of the final CFA was used to calculate mean scores for each school climate domain to be used as outcome variables in the multilevel model. The final measure included 15 items with the four domains including (1) School Community, five items referring to mutual respect among students and staff as well as sense of belonging; sample item: "I feel like I belong at this school; (2) Physical Safety, three items referring to student fights, bullying, and students roaming the halls during class time; sample item: "Students fighting is a problem at this school" (reverse scored); (3) Sense of Safety, four items referring to feeling safe at school and going to and from school, perceiving fair consequences and having someone to talk to about problems; sample item: "I feel safe at my school"; and (4) Institutional Environment, three items referring to the physical building being clean, well-lit, and students having access to the arts at school; sample item: "The school building is clean and well maintained." Overall climate was calculated by mean scores of the 15 items.

Although the factor structure of school climate measure was established to identify distinct subdomains within the overall climate score, mean scores for all school climate domains and overall climate were significantly, and positively correlated with one another ($p < 0.001$). The strength of correlations were lowest for Physical Safety with the other domains and overall climate (r-values range from 0.10 with Sense of Safety to 0.52 with Overall Climate). However, these correlations are to be expected given the large sample size and that measured domains are considered to be part of the overall construct of climate.

2.2.2. School building and school neighborhood predictors

We selected school and school neighborhood predictors that were hypothesized to be relevant to school climate based on theory and our prior review of the literature (See Supplementary File). Two of the authors reviewed available secondary datasets to select fixed effects, and then identified data within the same 12 months of the time frame that school climate data were selected (e.g., 2016–2017). See Table 3 for a list of all school and neighborhood variables tested as fixed effects on school climate, including their data source and operational definition. More information about these variables can be found *via* each of the data sources, including Great Schools,[1] Maryland School Report Card[2] and Baltimore Neighborhood Indicators Alliance.[3] All data were available in aggregate for either the school or community statistical area.

2.3. Sample

The resulting dataset included school climate surveys from 15,833 elementary students in third through fifth grade (ages 8–11 years old; Level 1). Student-level covariates of grade (3rd grade = 5,427, 34.3%; 4th grade = 5,315, 33.6%; 5th grade = 5,091, 32.2%; Missing = 0) and sex (Male, coded as "1" = 7,819, 49.4%; Female, coded as "0" = 7,921, 50.0%; Missing = 93, 0.6%). Students were nested within 124 Baltimore City Schools (Level 2) and those schools are in 55 community statistical areas (Level 2). Most elementary schools in Baltimore serve students living in very close geographic proximity of the school building. The year these data were collected, Baltimore was the U.S.'s 26th largest city with a population estimated at 622,793 people, and one of the poorest counties in the state, with 22% of people living below the poverty line (U.S. Census Bureau, 2016). City residents identify primarily as African American (63.7%), White (28.23%), and Hispanic/Latino (4.4%). However, there is an over representation of African American (81.8%) and Hispanic/Latino (8.2%) students in the public schools. The annual rate of violent crime in Baltimore is four times the national median rate and over three times the average rate in Maryland (Baltimore City Government, 2017). An adverse childhood experiences study found that children in Baltimore City were more likely than children nationwide or in Maryland to have experienced extremely stressful or traumatic events (Baltimore City Health Department, Commissioner of Health, 2017). Descriptive statistics on additional school building and school neighborhood predictors are displayed in Table 1.

2.4. Analytic strategy

Using SPSS version 28.0, we tested five cross-sectional, multilevel models with fixed and random effects using linear mixed effects modeling to assess which Level 2 school and neighborhood predictors were associated with student-reported school climate. One model was tested for Overall Climate and four additional models were tested for each of the domains of climate within the measure (i.e., School Community, Physical Safety, Sense of Safety, Institutional Environment) to understand if predictors were uniquely related to any of the domains. The model for each climate domain was specified independently (i.e., orthogonally). Variance estimation was restricted maximum likelihood (REML) and covariance matrix was unstructured. The outcome was the grand-mean centered, student-report of school climate; Level 1 covariates were student grade and sex; Level 2 included grand-mean centered school building- and school neighborhood-level predictors. The random effect of school was tested *via* inclusion of the random intercept. We opted not to include random slopes due to the cross-sectional design and Level 1 fixed effects serving as control variables or covariates (Barr et al., 2013). However, we acknowledge that there are different perspectives on whether fixed effects models are indeed the gold standard over random effects models, and whether random effects should be included in all cases or only when justified by the design (Bell et al., 2019).

We entered school building and school neighborhood predictors at the same level (i.e., Level 2) after intraclass correlations (ICCs) indicated limited variability across neighborhoods when entered at Level 3 (ICC range = 0 to 1.6%). ICCs for neighborhood predictors alone at Level 2 (without school variables) explained 12% of overall school climate ($p < 0.001$), so neighborhood variables were regarded as important to retain in the model. Therefore, taken together, we think about the Level 2 variables as "school building and school neighborhood predictors," both at the school level. Unconditional ICCs calculated based on intercept-only models showed school-level variation of 22.6% for Overall Climate, and slightly less variation for each domain of school climate (i.e., 14.3% for Community, 12.7% for Institution, 8.2% for Sense of Safety, and 18.2% for Physical Safety). With the full model including all Level 2 school and school neighborhood predictors, conditional ICCs revealed that variance was reduced by approximately half for Overall Climate (12.5%) and respective domains (i.e., 6.9% for Community, 5.4% for Institution, 3.4% for

1 www.greatschools.org

2 https://reportcard.msde.maryland.gov/

3 https://bniajfi.org/ and https://bniajfi.org/indicators/all

TABLE 3 School and neighborhood predictors tested as fixed effects on school climate.

Fixed effect	Data source	Operational definition
School level		
Student-teacher ratio	GS*	Average number of students per full-time teacher. Not a reflection of average class size.
Teacher 3+ years of experience	GS	Percent of full-time teachers with three or more years of experience
Certified teachers	GS	Percent of full-time teachers who have met all applicable state standard teacher certification requirements.
Enrollment	MSDE**	Number of students enrolled in the 2016–17 school year
Attendance	MSDE	Percent of days attended based on days enrolled. Less than 90% attendance is considered chronically absent.
Mobility	MSDE	Percent of students moving from one school to another during the school year.
Free and reduce meals (FARMS)	MSDE	Percent of students who quality for free and reduced meals based on family income and size in the 2016–2017 school year
Students in special education (SPED)	MSDE	Percent of students with a special education designation in the 2016–17 school year
Neighborhood level		
Shootings	BNIA***	Rate of 911 calls for shootings per 1,000 residents in an area. Possible that multiple calls could be made for one incident
Adult arrests	BNIA	The number of persons aged 18 and over arrested per 1,000 residents in an area. Predictor is calculated by where individual was arrested, not where the crime occurred
Dirty streets and alleys	BNIA	Rate of service requests for dirty streets and alleys made through Baltimore's 311 system per 1,000 residents. Possible that multiple calls could be made for one incident
Clogged storm drains	BNIA	Rate of service requests for addressing clogged storm drains made through Baltimore's 311 system per 1,000 residents. Possible that multiple calls could be made for one incident
Female-headed households with children	BNIA	Rate of female-headed households with children under 18 out of all households with children under 18 in an area
Median household income	BNIA	Middle value of incomes earned in the prior year by households within an area. Income and earnings are inflation-adjusted. Median is used to avoid distortion from extreme high and low values
Narcotics calls	BNIA	Rate of 911 calls for narcotics per 1,000 residents in an area. Possible that multiple calls could be made for one incident
Violent crime	BNIA	Number of Part 1 crimes identified as being violent (homicide, rape, aggravated assault, and robbery) that are reported to the Police Department per 1,000 residents in the area
Residential properties vacant/abandoned	BNIA	Percent of residential properties that have been classified as vacant and abandoned by Baltimore City Department of Housing out of all properties. This includes property is not habitable and boarded up or open to elements, designated as being vacant prior to the current year and remains vacant, or multi-family structure where all units are considered vacant
Employed adults	BNIA	Percent of persons aged 16–64 formally employed or self-employed earning a formal income

*GS = Great Schools, www.greatschools.org was referenced for the data; primary source is the Civil Rights Data Collection, https://ocrdata.ed.gov/.
**MSDE = Maryland State Department of Education, 2017 Maryland School Report Card, https://reportcard.msde.maryland.gov/.
***BNIA = Baltimore Neighborhood Indicators Alliance, https://bniajfi.org/ and https://bniajfi.org/indicators/all.

Sense of Safety, and 11.3% for Physical Safety). The multilevel model equation and SPSS code are provided in the Supplementary File to promote reproducibility.

3. Results

Data were inspected for normality of distributions among all predictor (i.e., fixed effects) and outcome variables. Overall, there were low levels of variable-level missingness on the school climate survey and predictor variables, with the percentage of missing data across variables ranging from 0 to 10%, and the largest percentage of missingness for school-building variables. School climate scores were normally distributed and ranged from 0 to 1 ($M = 0.561$; $SD = 0.21$ for Overall Climate, see Table 1 for all domains), with an average of 127 responses per school. Individual school climate domains evidenced slight negative (i.e., Community, Institutional Environment, Sense of Safety) or positive skew (i.e., Physical Safety) that was within acceptable limits (skew < |1|; see *M* and *SD* in Table 1). The response range for school climate items did not indicate ceiling or floor effects (average percentage agreement ranged from 27 to 85%) indicative of potential response bias. However, we are unable to account for potential selection bias of surveys completed by students. We examined Pearson correlations for all predictor variables; all variables were significantly related ($p < 0.05$), which is to be expected due to the large sample size, and in the expected direction (e.g., teachers with 3+ years of experience and certified teachers $r = 0.76$; FARMS and mobility $r = 0.73$; attendance and mobility $r = -0.62$). Correlation values ranged from absolute values of $r = 0.004$ (students in special education and violent crime; students in special education and arrests) to $r = 0.86$ (rate of narcotics calls and arrests), which were approximately normally distributed around a median of absolute value $r = -0.266$. The strength of the correlations had an absolute value of $r = 0.32$ on average. Table 1 includes descriptive statistics for all model predictors and outcomes. In addition to information in "Sample" about the community demographics, including high rates of violent crime and trauma exposure as compared to the United States national average in this large, urban school system, school building and school neighborhood characteristics in Table 1 also provide important context for this study. Notably, school size varied widely (range = 39–1,366), and although schools on average had 80% of teachers with 3+ years of experience, the mean percentage of certified teachers by school was 1.7%. As this is a high poverty area where students and families experience complex socioeconomic challenges, mean mobility rate was 31% (up to 73% by school) and most students qualified for free and reduced meals (63% on average and up to 91% by school). Table 4 includes outcomes for all multilevel models.

Among the Level 1 covariates, grade was significantly associated with Overall Climate and all four subdomains ($p < 0.001$), such that higher grades (e.g., 5th grade or students approximately 10 years old) reported lower climate than students 1 or 2 years younger. The Physical Safety domain was the only exception in that the direction of the relation was positive. Student sex was significantly related to School Community ($p < 0.001$) and Sense of Safety ($p < 0.05$), with positive School Community more frequently reported by male-identifying students and positive Sense of Safety more frequently reported by female-identifying students. When controlling for Level 1 covariates, there were multiple school building and school neighborhood variables that explained a statistically significant amount of variation in Overall Climate and its domains (see Table 4). The five statistically significant predictors of Overall Climate and three of four school climate domains were attendance rate (B ranging between 0.008 to 0.020), mobility rate ($B = -0.003$ to -0.002), students in special education ($B = 0.001$ to 0.004), number of shooting calls for service ($B = 0.022$ to 0.044), and rate of calls for dirty streets and alleys ($B = <0.001$ to 0.001). Attendance rate was the only statistically significant predictor of School Climate ($B = 0.015$, $t = 3.75$, $p < 0.001$), and all four domains, such that higher school-level attendance rate predicted more positive student reports of climate. There were five statistically significant school-level predictors of School Community, including teacher years of experience ($B = 0.003$), certified teachers ($B = -0.003$), attendance ($B = 0.018$), mobility ($B = -0.003$), students in special education ($B = 0.003$); and two statistically significant community-level predictors, including shootings ($B = 0.030$), dirty streets and alleys ($B < 0.001$). Sense of Safety (SoS) and Institutional Environment (IE) showed similar patterns, with attendance rate (SoS $B = 0.013$; IE $B = 0.008$), mobility rate (SoS $B = -0.002$; IE $B = -0.003$), students in special education (SoS $B = 0.004$; IE $B = 0.003$), shootings (SoS $B = 0.022$; IE $B = 0.044$), adult arrest rate (SoS $B = -0.003$; IE $B = -0.004$), and dirty streets and alleys (SoS $B < 0.001$) serving as statistically significant predictors. The only statistically significant predictor of Physical Safety was attendance rate ($B = 0.020$, $t = 2.77$, $p < 0.01$). Note that mobility was measured at the school level but could be conceptualized as a school neighborhood predictor due to its tie to family economics that occurs in the broader school neighborhood context.

4. Discussion

School climate and neighborhood characteristics significantly predict students' academic, social–emotional, and behavioral outcomes (Chetty and Hendren, 2015; Wang and Degol, 2016). Moreover, school climate may buffer the influence of neighborhood-level risk factors on student outcomes (Ozer et al., 2010; O'Donnell et al., 2011), particularly in school communities where students and families face socioeconomic stressors and high rates of exposure to community violence (McCoy et al., 2013; Ruiz et al., 2018). As such, understanding how school building and school neighborhood characteristics relate to student perceptions of school climate may signal directions in future research and practice to promote positive school climate to foster student academic achievement and well-being. This study examined the relation between structural factors at school building and school neighborhood levels with student perceptions of school climate (i.e., Overall Climate, School Community, Institutional Environment, Sense of Safety, Physical Safety) in a large, urban school district. We used multilevel modeling so school building and school neighborhood fixed effects were entered in the models as predictors of school climate, although we interpret the significant results as associations because the data were cross-sectional, not longitudinal. Overall, we found that various structural school building and school neighborhood factors were associated with student-perceived school climate in this sample.

Our results relate to two central theories in understanding the influence of neighborhood and school factors on students' school experiences. One is Social Disorganization Theory, which posits that neighborhood structural characteristics (e.g., poverty, residential instability) break down social ties and neighborhood organization which in turn results in undesired individual outcomes and behaviors (e.g., crime, delinquency); (Shaw and

TABLE 4 Multilevel models predicting student-reported school climate.

	Overall climate		School community		Physical safety		Sense of safety		Institutional environment	
	β	*SE*	*β*	*SE*	*β*	*SE*	*β*	*SE*	*β*	*SE*
Level 1										
Intercept	0.733***	0.012	0.878***	0.017	0.288***	0.022	0.813***	0.015	0.838***	0.015
Student-level covariates										
Grade (3,4,5)	−0.030***	0.002	−0.060***	0.003	0.013***	0.004	−0.019***	0.003	−0.037***	0.003
Sex (Male = 1, Female = 2)	−0.006	0.003	−0.025***	0.005	−0.010	0.006	0.011*	0.005	0.006	0.005
Level 2										
School building and school neighborhood fixed effects										
Student–teacher ratio	0.002	0.003	0.003	0.004	0.002	0.006	0.002	0.003	0.002	0.003
Teacher 3+ years experience	0.002*	0.001	0.003**	0.001	0.002	0.002	0.002**	0.001	0.001	0.001
Certified teachers	−0.001	0.001	−0.003*	0.001	<−0.001	0.002	−0.001	0.001	<−0.001	0.001
Enrollment	<−0.001	<0.001	<0.001	<0.001	−0.001	<−0.001	<0.001	<0.001	<−0.001	<0.001
Attendance rate	0.015***	0.004	0.018***	0.004	0.020**	0.007	0.013***	0.003	0.008*	0.004
Mobility rate	−0.002*	0.001	−0.003**	0.001	−0.002	0.002	−0.002*	0.001	−0.003**	0.001
Free and reduced meals	<−0.001	0.001	<−0.001	0.001	−0.001	0.002	<0.001	0.001	0.001	0.001
Students in special education	0.003*	0.001	0.003*	0.001	0.001	0.002	0.004**	0.001	0.003*	0.001
Shootings	0.032*	0.013	0.030*	0.014	0.036	0.024	0.022*	0.010	0.044**	0.012
Adult arrests	−0.003	0.001	−0.002	0.002	−0.001	0.003	−0.003*	0.001	−0.004**	0.001
Dirty streets and alleys	<0.001*	<0.001	<0.001*	<0.001	0.001	<0.001	<0.001*	<0.001	<0.001	<0.001
Clogged storm drains	−0.007	0.008	−0.007	0.009	−0.006	0.015	−0.003	0.007	−0.015	0.008
Female-headed households	−0.001	0.001	−0.001	0.001	<−0.001	0.001	−0.001	0.001	<−0.001	0.001
Median household Income	<0.001	<0.001	<−0.001	−0.001	−0.001	<−0.001	<0.001	<0.001	<0.001	<0.001
Narcotics calls	<0.001	<0.001	<−0.001	<0.001	<−0.001	0.001	<0.001	<0.001	<0.001	<0.001
Violent crime	0.001	0.002	0.001	0.002	−0.002	0.004	0.001	0.001	0.004	0.002
Residential properties vacant/ abandoned	−7.028	0.002	<−0.001	0.002	−0.001	0.003	0.001	0.001	<0.001	0.002
Employed adults	4.404	0.002	<0.001	0.002	−0.002	0.003	<−0.001	0.001	0.001	0.001

****p* < 0.001; ***p* < 0.01; **p* < 0.05.

McKay, 1942). There is an historical assumption in the literature that indicators of community "disorder" or lack of safety unquestionably have a negative effect on school safety and climate (McCoy et al., 2013). However, empirical evidence highlights the potential for positive school climate to interrupt the negative association between detrimental neighborhood factors and students' academic and wellness outcomes (e.g., Gaias et al., 2019). This is consistent with our results, which show variation in school climate across schools despite limited variation in neighborhood risk factors, highlighting that some schools can create positive school climate despite a high level of instability in the surrounding neighborhood. This aligns with Social Control Theory, which focuses on the quality of social bonds that can decrease the likelihood of deviant behavior when exposed to external risk factors (Hirschi and Gottfredson, 1993). As applied to school climate, this suggests that students' attachment, involvement and commitment to the school community and its moral code may protect against potential neighborhood-level risks.

Of the structural school factors examined, student attendance rate and mobility were each associated with School Climate, including Overall Climate and the subdomains of School Community, Physical Safety, Sense of Safety, and Institutional Environment. Our results parallel prior research, such that higher attendance rates and lower mobility rates were associated with more positive student perceptions of school climate (e.g., Bradshaw et al., 2009; Van Eck et al., 2017). Applying Social Disorganization Theory, high rates of student absenteeism and student mobility in the school community may indicate to students that their school environments are unstable or unsupportive (Bradshaw et al., 2009; Plank et al., 2009), which may challenge their feelings of connection with their school—contributing to less positive perceptions of their school's climate (Lindstrom Johnson et al., 2016). For example, Green et al. (2019) found lower odds of school connectedness for students with high residential mobility among a sample of 5,620 public elementary school students in Los Angeles County. This is critical given the importance of healthy relationships and school connectedness in promoting positive school climate (CDC, 2009). Attendance and mobility rates may also reflect family socioeconomic conditions, including housing instability, lack of transportation, or irregular work schedules that contribute to student absences (Durham and Connolly, 2017). Alternatively, drawing on the importance of quality social bonds in Social Control Theory, schools' efforts to support student attendance, for example through building relationships with families or focusing on and celebrating improvement (as opposed to punitive measures), can have positive impacts on their school's climate (Durham and Connolly, 2017). Thus, it may be that schools in this study with higher attendance rates were actively engaged in similar efforts to support student attendance, thereby contributing to students' more positive perceptions of climate. However, additional research is needed to understand the directionality of the relations between attendance, mobility, and climate. For example, it may be that students regular and consistent attendance during the academic year fosters positive school climates. Conversely, students may be more likely to attend school when they perceive the climate positively (Van Eck et al., 2017). However, as our sample is elementary age, attendance and mobility are most likely occurring within the context of a family system and the relationship between the family and the school as much as the student-school relationship or engagement. Of note, in our sample, mobility and attendance were moderately correlated in the expected direction ($r = -0.62$), indicating that mobility could be a proxy for housing instability and other types of family instability which could also predict attendance rates. Logically, attendance problems and/or mobility may contribute to students having more difficulty feeling connected to the school community itself.

In addition to school attendance and mobility, the other two school factors significantly associated with school climate (though less consistently significant across school climate domains as compared to attendance and mobility) was teacher years of experience and students in special education. Teacher years of experience was positively related to School Community, Sense of Safety, and Overall Climate, such that students attending schools with a greater percentage of full-time teachers with three or more years of experience were more likely to report a more positive climate in these domains. Previous research supports the connection between teacher experience and student perceptions of school climate (La Salle et al., 2015), such that teacher years of experience may correlate with other structural school factors that have been significantly associated with school climate, such as punitive and exclusionary referrals and classroom management practices (Thapa et al., 2013). Higher percentages of new teachers may also be an indicator of high teacher turnover, which can contribute to a sense of educational and relational instability for students (Ingersoll, 1999). Number of students enrolled in special education was also positively related to Overall Climate and to School Community, Sense of Safety, and Institutional Environment. It is plausible that schools with more staff, resources, and/or supports to serve students who require special education may have other related institutional supports that promote positive school climate. These results may also have been impacted by correlations across predictors, as several of the other statistically significant predictors of school climate (i.e., student mobility and attendance rates as well as teacher education) have also been associated with increased special education enrollment in previous studies (e.g., Talbott et al., 2011).

Student-teacher ratio, number of students enrolled, and percent of students who qualify for free and reduced priced meals were not observed to be related to student perceptions of school climate in this study. Percent of full-time teachers who were certified teachers was negatively related to School Community, but not related to other domains of climate. There are mixed findings in the literature regarding the association between these factors and school climate or student outcomes, warranting additional research with additional samples (Bradshaw et al., 2009; DeAngelis and Presley, 2011; Thapa et al., 2013), while also highlighting the need for localized examination of school climate predictors using analytic models similar to the approach used in this paper.

Considering relations between school neighborhood factors and student-perceptions of school climate, some school neighborhood factors (i.e., shootings, adult arrest rate, dirty streets and alleys) were associated with Overall Climate and various subdomains of school climate, except Physical Safety. For example, more shooting reports were associated in the unexpected direction with higher student perceptions of Institutional Environment at their school (i.e., building cleanliness and lighting, access to extracurriculars), students' Sense of Safety (i.e., feeling safe at school) and perceptions of the School Community (i.e., mutual respect, school belonging), as well as Overall Climate. Reports of dirty streets and alleys was also associated with higher student perceptions of Institutional Environment and Sense of Safety. The strength of these associations are small, so perhaps are most appropriately interpreted as signals in this large dataset that various neighborhood safety and environmental factors are related to school climate and worthy of future study and replication. One possible explanation for this is that many of the neighborhood factors are resident-reported. Notably, the rate of adult arrests, which is an objective measure (not resident reported) was associated in the expected direction with lower student perceptions of Institutional Environment and Sense of Safety. Studies conducted in the United States and abroad suggest that social cohesion and perceptions of police effectiveness positively influence crime reporting in neighborhoods (Goudriaan et al., 2005). Other research indicates that collective efficacy of a neighborhood and residents' sense of connectedness are related to concerns about neighborhood safety in high-crime neighborhoods (Pitner et al., 2012). Thus, the positive association between school neighborhood crime and environmental sanitation reports with school climate might signal the strengths of neighborhood cohesion and sense of community to report neighborhood concerns that may influence the broader school-community context and students' positive perceptions of school climate. Of note, during this time in Baltimore City, there was a 24/7 non-emergency community number enabling residents to report community concerns to be addressed by city officials. Thus, resident-reported neighborhood factors may vary in their associations with school climate depending on the system and structure for those instances to be reported. Of course, these associations found in our sample do not necessarily generalize to other school communities or districts given the variability of community and school characteristics, and warrant replication in other school-community contexts.

4.1. Implications for school systems and leaders

School climate data are often available to school and district leaders and teams if school climate surveys are conducted. However, there are limitations in terms of how school climate data can be interpreted and used. School systems and leaders may want to clarify the purpose of school climate data for their quality improvement efforts, and whether they consider school climate as a predictor of student outcomes, mediator of school or neighborhood factors on student outcomes, or outcome of its own. School climate is argued to be both an important outcome, for example, as a non-academic indicator of school quality (U.S. Department of Education, 2022a; Temkin et al., 2021), and as critical predictor of students' academic achievement and well-being (Wang and Degol, 2016). Schools may build school climate into quality improvement initiatives or as a process or outcome evaluation variable of other implementation efforts, but because school climate is such a complex construct, schools might want to study and/or target specific aspects of climate at a time. There is a growing compendium of tools and technical assistance based on case studies supporting schools and school leaders in disadvantaged and stressed neighborhoods to retain staff and support positive student development and success (e.g., WestEd, 2022).

Also, given the potential protective effects of school climate for students and school communities, and bolus of research on resilient students, families, and school communities despite contextual adversities and resource constraints, it is important to avoid deficit-based assumptions that school climate is necessarily determined by the structural characteristics of the school and surrounding community. Schools in our sample had a wide range of school climate scores despite consistently high school neighborhood crime rates and other structural risk factors such as low socioeconomic status throughout the city. A more nuanced understanding of the influence of various community and school characteristics on school climate opens the door to opportunities for school climate reform and promoting students' feelings of safety and belonging at school. There are numerous field examples of highly-resilient schools and districts displaying positive school culture and climate despite substantial community safety concerns, particularly in urban, low-income districts (e.g., Fryer and Dobbie, 2011). Our results indicate that student attendance is significantly associated with school climate in Baltimore schools. Therefore, efforts to improve attendance may improve school climate, such as the field example of how this was done using a Community Schools Model in Baltimore City (Durham and Connolly, 2017).

We hope for continued research on the associations between neighborhood factors, school factors, and school climate, which may help identify levers for change to build resilient schools in under-resourced and highly stressed communities. We also encourage school systems and leaders to think about their school climate data not just as a reflection on their school, but an important indicator of student sense of connection and well-being which can also be influenced by family socioeconomic factors and neighborhood risk and protective factors.

4.2. Limitations and future directions

The results of this study are interpreted within the context of notable limitations. Principally, despite the importance of school climate in supporting student learning outcomes, there is not currently a universally-accepted definition of school climate (Wang and Degol, 2016). There is great variability in how the multidimensional school climate construct is defined and subsequently operationalized in measures administered to students and staff (Wang and Degol, 2016). For this study, we undertook a theoretically-driven, iterative approach to validate the internal structure of a local school climate survey. We identified a measurement model, comprised of four school climate domains, with acceptable fit that excluded several non-theoretically relevant or poorly-loading survey items; this underscores the need to continue to improve measurement of school climate in research and practice *via* theoretically-aligned, reliable, and valid measures (Ryberg et al., 2020; Grazia and Molinari, 2021; Temkin et al., 2021). Our process of construct validation prior to examining associations of interest is a notable strength of this research. However, the associations we observed between school and neighborhood factors with Overall Climate and the domains of School Community, Institutional Environment, Sense of Safety, and Physical Safety may not generalize to other school districts and contexts in which school climate has been defined and operationalized differently.

Second, guided by our review of the literature, we included many fixed effects in our multilevel models as potentially related to school climate. Examination of a correlation matrix signaled potential multicollinearity among some variables included as fixed effects (i.e., largest $r = 0.83$). However, parameter estimates in 2-level multilevel models are not biased by multicollinearity, multicollinearity may impact standard errors of these estimates which could impact statistical significance among predictors with shared variance (Shieh and Fouladi, 2003). We also acknowledge that several predictors were similarly predictive across overall climate and respective domains. This is to be expected as the domains are distinct yet correlated with one another and part of the same construct of overall climate. We selected predictors based on theory and previous research instead of quantitatively. This was done in part because we had access to a very large number of possible predictors in these secondary datasets and wanted to be sure to select based on what theory and extant literature suggested as likely related to school climate. In line with this goal, we opted not to use actuarial methods to select predictors nor to test additional models with a subset of fixed effects. We retained non-significant fixed effects in the model which are displayed in Table 4 to promote transparency for future studies that may consider these factors. Our analyses are not intended to assess generalizable causality of school factors on climate, but rather to signal factors that local school systems might want to examine as potential quality improvement targets. Future research may consider testing a more parsimonious model or pursuing data reduction to include fewer fixed effects, and comparing model results using information criterion statistics.

Third, although several school and neighborhood factors were statistically significantly associated with school climate (overall scores and subdomains), the magnitude of effects was small and model intercepts were comparably large. This suggests that there are student- and school-level factors associated with school climate that are not represented in our model based on our available data sources. For example, this study examined primarily structural school and neighborhood factors, given their priority in school and district assessments of school climate and student outcomes (Gottfredson et al., 2005; Rudasill et al., 2018; Laurito et al., 2019). However, theory and prior research (e.g., Social Control Theory; (Hirschi and Gottfredson, 1993) highlight the importance of relational factors, including strong bonds between students and their school, in promoting positive climate. The school characteristics (i.e., student mobility and attendance, teacher years of experience) that were most strongly associated with school climate in the current study have the potential to contribute to or prohibit the development of consistent relationships between peers and between students and teachers. However, the associations we observed may be limited in their generalizability to schools and districts with different characteristics and student populations (e.g., secondary schools). For example, whereas the schools serving elementary students in our sample, on average, employed many teachers with more than 3 years of experience, schools also tended to have a low percentage of certified teachers (see Table 1). The association between mobility and attendance, student connectedness and relationships, and school climate should be examined longitudinally to better understand these associations. Moreover, La Salle et al. (2015) underscore the importance of individual (e.g., race/ethnicity, resources) and family (e.g., socioeconomic status, values) cultural factors that are important for understanding school climate and its relation with student outcomes. It will be important for future work to replicate and extend our findings by including relational, personal, and contextual characteristics and with additional districts that vary in size, urbanicity, geographic region, and staff characteristics.

Finally, given the cross-sectional nature of this study, we are unable to determine the directionality of the relations observed between structural school factors and school climate. Although we positioned school climate as the 'outcome' variable and the school and neighborhood factors as 'predictors', longitudinal investigations of the influence of school and neighborhood factors on school climate are needed. Longitudinal designs with multiple timepoints and larger sample sizes can also enable examination of interactions between neighborhood and school factors in predicting school climate. Through this work, school and community stakeholders can better understand what predicts positive school climate in their local context, and extend this work to examine how school climate may buffer against school and neighborhood risk factors.

Previous research highlights mixed findings regarding the association of neighborhood and school factors with school climate and student outcomes. This may be due in part to differences in how these constructs are measured as well as geographic differences. School districts also use a wide array of school climate measures (e.g., Grazia and Molinari, 2021), limiting the ability to examine for collective trends across school districts. Schools also frequently have limited data support, prohibiting them from thoroughly exploring their school climate data. This highlights the importance of school district-research partnerships to analyze and interpret school climate data. Increasing access to universal school climate measures that can be collected across school districts would also enable expanded learning across geographic areas. The current study illustrates one method that school districts can use, likely with the assistance of academic research partners or in some cases their internal data team, to understand school climate data. Through increased use of universal school climate measures, the field can also begin to examine for trends across school districts, geographic areas, states, and countries as we expand our knowledge of how to promote positive and effective school climates.

Data availability statement

The datasets generated and analyzed for this study are a combination of school district data used for quality improvement and public-domain data. The publicly available data can be obtained from Great Schools (www.greatschools.org), Maryland School Report Card (https://reportcard.msde.maryland.gov/), and Baltimore Neighborhood Indicators Alliance (https://bniajfi.org/ and https://bniajfi.org/indicators/all). Access to the data files used for this study may be granted by the authors upon reasonable request.

Author contributions

SM developed the research questions and analytic approach with EC, conducted the school climate survey factor analysis, identified school building, and school neighborhood variables to add to the model based on literature review, requested, cleaned, and merged secondary data to build the dataset, reviewed and supported writing of all sections, and wrote the discussion. SM is the primary author and co-led the project. RO wrote the introduction, reproduced multilevel models, and checked them for accuracy, created tables, reviewed, and provided feedback on all written sections. EC developed the research questions and analytic approach with SM, identified school building and school neighborhood variables to add to the model based on literature review conducted the multilevel models, reviewed, and supported writing of all sections, and wrote the discussion. EC is the senior author and co-led the project with SM. All authors discussed the results and contributed to the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.931474/full#supplementary-material.

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EDITED BY
Parisa Parsafar,
Eunice Kennedy Shriver National Institute of Child Health and Human Development (NIH), United States

REVIEWED BY
Vanessa Arán Filippetti,
National Scientific and Technical Research Council (CONICET), Argentina
Elizabeth Votruba-Drzal,
University of Pittsburgh, United States

*CORRESPONDENCE
Prachi E. Shah
prachis@umich.edu

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Ecological contexts associated with early childhood curiosity: Neighborhood safety, home and parenting quality, and socioeconomic status

Prachi E. Shah[1,2]*, Kathy Hirsh-Pasek[3], Maria Spinelli[4], Jenny Ozor[5], Heidi M. Weeks[6], Harlan McCaffery[1] and Niko Kaciroti[1,7]

[1]Division of Developmental-Behavioral Pediatrics, Department of Pediatrics, University of Michigan Medical School, Ann Arbor, MI, United States, [2]Department of Psychiatry, University of Michigan Medical School, Ann Arbor, MI, United States, [3]Department of Psychology, Temple University, Philadelphia, PA, United States, [4]Department of Neuroscience, Imaging and Clinical Science, University Gabriele d'Annunzio Chieti-Pescara, Chieti, Italy, [5]Department of Public Policy and Government Affairs, CareFirst Blue Cross Blue Shield, Washington, DC, United States, [6]Department of Nutritional Sciences, School of Public Health, University of Michigan, Ann Arbor, MI, United States, [7]Department of Biostatistics, University of Michigan, Ann Arbor, MI, United States

Introduction: Curiosity is an important social-emotional process underlying early learning. Our previous work found a positive association between higher curiosity and higher academic achievement at kindergarten, with a greater magnitude of benefit for children with socioeconomic disadvantage. Because characteristics of the early caregiving and physical environment impact the processes that underlie early learning, we sought to examine early environmental experiences associated with early childhood curiosity, in hopes of identifying modifiable contexts that may promote its expression.

Methods: Using data from a nationally representative sample of 4,750 children from the United States, this study examined the association of multi-level ecological contexts (i.e., neighborhood safety, parenting quality, home environment, and center-based preschool enrollment) on early childhood curiosity at kindergarten, and tested for moderation by socioeconomic status.

Results: In adjusted, stratified models, children from lower-resourced environments (characterized by the lowest-SES tertile) manifested higher curiosity if they experienced more positive parenting, higher quality home environments, and if they lived in "very safe" neighborhoods.

Discussion: We discuss the ecological contexts (i.e., parenting, home, and neighborhood environments) that are promotive of early childhood curiosity, with an emphasis on the role of the neighborhood safety and the "neighborhood built environment" as important modifiable contexts to foster early childhood curiosity in lower-resourced families.

KEYWORDS
curiosity, ecological contexts, neighborhood safety, socioeconomic status, parenting quality, home environment

Introduction

Curiosity is a fundamental human motivation that influences learning, the acquisition of knowledge, and life fulfillment (Kashdan et al., 2020), and in children, is believed to be a critical social-emotional process underlying academic achievement (Lepper et al., 2005). Curiosity is described as the motivational drive to seek out information in new, uncertain, or complex situations (Loewenstein, 1994; Litman, 2005; Jirout and Klahr, 2012), and in young children, it is often expressed by exploratory behavior (Berlyne, 1954), novelty seeking (Berlyne, 1960), and the joy of learning. Higher curiosity has been associated with adaptive outcomes throughout the lifespan, including better academic and interpersonal outcomes in middle childhood (Maw and Maw, 1975; Lepper et al., 2005), adolescence (Kashdan and Yuen, 2007; Jovanovic and Brdaric, 2012; Froiland et al., 2015), and adulthood (Kashdan and Steger, 2007; Kashdan et al., 2013a). Given the beneficial outcomes associated with curiosity across the life-course, we were interested in examining the environmental contexts associated with higher curiosity in *early childhood*.

In our prior work, using data from a nationally representative sample of 6,200 children from the United States, we examined the association between parent-reported curiosity and kindergarten academic achievement. We found a positive association between higher curiosity and higher academic achievement in reading and math at kindergarten, with a greater magnitude of benefit for children with socioeconomic disadvantage (Shah et al., 2018). Our results demonstrated that while higher curiosity was associated with higher academic achievement in *all children*, low-income children with higher curiosity demonstrated the greatest gains in academic achievement, with the achievement gap between high and low-income children essentially eliminated at high levels of early childhood curiosity. One implication from this work was the possibility that promoting curiosity in young children could be one way to mitigate the achievement gap associated with poverty, although the contexts associated with the promotion of curiosity have been relatively understudied (Hassinger-Das and Hirsh-Pasek, 2018).

Curiosity is a multidimensional construct that is both person-specific (i.e., trait curiosity) and situation-specific (i.e., state curiosity). While *trait curiosity* is related to aspects of personality which are highly heritable and less influenced by context (Steger et al., 2007), *state curiosity* is related to an individual's interests, whose expression can vary with context and experiences (Black and Deci, 2000; Kashdan and Fincham, 2004; Ainley, 2019). Currently, we have a limited understanding of the contexts which can foster early childhood state curiosity, especially in children from under-resourced environments. Addressing this knowledge gap can lead to targeted interventions to support the expression of early childhood curiosity, which could have implications for early academic achievement.

Ecological theory (Brofenbrenner, 1993) has identified the multilevel contexts and social experiences which influence early child development. These contexts include the quality of experiences in the *proximal* (microsystem) environment (e.g., *early parent-child relationship* (Sroufe, 2005), *home environment* (Crosnoe et al., 2010), and *early educational environment* [Fuller et al., 2017)]; the *distal* (mesosystem) environments (e.g., *the safety of the neighborhood* in which children live [Minh et al., 2017)]; and the *macro contexts* (macrosystem) associated with poverty and socio-economic disadvantage (Brooks-Gunn and Duncan, 1997; Heckman, 2006; Hyde et al., 2020). We theorize that the ecological contexts associated with more optimal *early learning* may also be relevant for the promotion of *early childhood curiosity*.

Proximal contexts associated with better school readiness skills include more sensitive early parenting (Frick et al., 2018; Snijders et al., 2020), more stimulating home environments (Rodriguez and Tamis-LeMonda, 2011; Hirsh-Pasek et al., 2015a) and enrollment in center-based preschool (Fuller et al., 2017). Because curiosity is fostered in environments which promote inquiry and align with a child's individual interests, we hypothesize that more positive parenting (characterized by greater sensitivity and cognitive stimulation), more stimulating home environments, and enrollment in preschool may be similarly promotive of early childhood curiosity.

Distal and macro ecological contexts salient to early childhood development relate to the socioeconomic conditions in the child's neighborhood environment, including poverty and neighborhood safety (Leventhal, 2018). Neighborhoods characterized by poverty, disadvantage, and lower neighborhood safety have been associated with lower academic achievement (Leventhal et al., 2015), more behavior problems (Leventhal and Brooks-Gunn, 2000), and structural differences in brain development contributing to impaired emotion regulation (Hyde et al., 2020), although associations with early childhood curiosity have not been examined. Curiosity is characterized by the drive to seek out new information (Loewenstein, 1994) and the desire to explore (Jirout and Klahr, 2012). Because neighborhoods are a salient ecological context for play, exploration, and learning, characteristics of the neighborhood environment, especially *neighborhood safety*, may have implications for the expression of curiosity by fostering or deterring children's ability to play and explore.

There is some empirical support linking parents' perceptions of neighborhood safety and children's play behavior, especially for under-resourced children. Low-income mothers who rated their neighborhood as unsafe or unpredictable were less likely to allow their children to play outside, citing that survival (in a high-crime neighborhood) was a higher priority than outdoor play (Dias and Whitaker, 2013). Other studies have similarly suggested an association between parents' perception of neighborhood safety and parents' promotion of outdoor play, with decreased frequency of outdoor play associated with increased parent concerns about neighborhood safety (Kalish et al., 2010; Galaviz et al., 2016).

Relatedly, in our previous work, we observed an "achievement gap" in low-income children who were rated as having lower parent-reported curiosity (Shah et al., 2018). One potential explanation for these findings is that children from under resourced environments may prioritize safety over exploration, which can contribute to the observed achievement gap compared to their more-curious peers (Hassinger-Das and Hirsh-Pasek, 2018). Neighborhood environments which are safer may contribute to greater exploratory behavior, resulting in higher early childhood curiosity. Critically, if greater neighborhood safety is associated with higher early childhood curiosity, this could lead to the development of interventions to optimize neighborhood environments (e.g., through attention to the quality of the built environment), to promote social-emotional processes related to early learning. This is notable because while some contexts associated with early academic achievement (e.g., genetics) are *relatively* immutable, the expression of early childhood curiosity may be malleable with context, and can vary according to the child's early experiences in the home, early education and neighborhood environments. Identifying the modifiable contexts associated with higher curiosity can lead to the development of interventions to support the expression of early childhood curiosity, which can potentially foster early academic achievement.

The aims of this study were to examine the proximal and distal ecological contexts of early childhood (i.e., parenting quality, quality of the home environment, enrollment in center-based preschool and neighborhood safety), and associations with curiosity at kindergarten, and to test for moderation by socioeconomic status (SES). We hypothesized that early experiences characterized by more positive parenting, higher quality home environments, enrollment in center-based preschool, or greater neighborhood safety would be associated with higher early childhood curiosity, with potentially magnified effects in children with socioeconomic disadvantage.

Materials and methods

Study design and sample

Data were drawn from the Early Childhood Longitudinal Study, Birth Cohort (ECLS-B), a nationally representative, population-based longitudinal study sponsored by the US Department of Education's National Center for Education Statistics (NCES). The ECLS-B is based on a nationally representative probability sample of children born in the United States in 2001 (inclusive). Data were collected from children and their parents at 9 months, 24-months, preschool and kindergarten timespoints, and included home visits with parent interviews, and direct and indirect child assessments across multiple settings (Snow et al., 2009). Our sample excluded children with congenital and chromosomal abnormalities, and included children born at 22–41 weeks gestation who had parental kindergarten behavioral data from which we could derive a measure of curiosity. Our study utilized data from birth certificate data, 24-months, preschool and kindergarten timespoints, and our final analytic sample included 4,750 children who had curiosity data at kindergarten, data on neighborhood safety, and all predictors and covariates (described below). This study was considered exempt by the Institutional Review Board because it involved the use of a publicly available dataset with de-identified participants who could not be linked to the data. Sample characteristics are described in **Table 1**.

Measures

Outcome

Early childhood curiosity

Because the ECLS-B did not have a measure to examine curiosity, we derived a measure of curiosity from an existing assessment of child behavior from the kindergarten timepoint, which included questions from the Preschool and Kindergarten Behavioral Scales Second Edition (PKBS-2). While we were limited by the questions that were available on the parent PKBS-2 questionnaire, we drew from previous theoretical work and behavioral descriptions of curiosity in young children to select question items that most closely aligned with characteristics of curiosity. While there is no single definition of curiosity (Kidd and Hayden, 2015), there are certain behavioral characteristics of curiosity that are widely accepted, including, (1) the thirst for knowledge, and the drive to understand what one does not know (Hall and Smith, 1903; Jirout and Klahr, 2012); (2) an exploratory drive to seek novelty (Berlyne, 1954); (3) an openness to new experiences (Maw and Maw, 1966); and, in young children, (4) innovation in exploratory play (Schulz and Bonawitz, 2007; Cook et al., 2011). Four question items from the PKBS-2 which aligned with these characteristics of curiosity were chosen for our "curiosity factor" (**Appendix A**). At the kindergarten timepoint, parents were asked to report the frequency of behaviors observed in the previous 3 months on a 5-point Likert scale (1, never to 5, very often). Items were reverse coded as appropriate such that higher scores indicated more positive behaviors. A confirmatory factor analysis (CFA) was conducted to

TABLE 1 Maternal/Home and child characteristics.

Maternal/Home characteristics	Mean, *SD* or Weighted%
Age (years)[a]	27.4, *5.3*
Race/Ethnicity[b]	
White/Non-Hispanic	59.9%
Black/Non-Hispanic	13.6%
Hispanic	20.8%
Asian	3.1%
Other	2.6%
Marital status[a]	
Married	69.2%
Unmarried	30.8%
Socioeconomic status at kindergarten[e]	−0.01, *0.96*
Parenting quality (sensitive, scaffolding, stimulating parenting)[c]	4.4, *1.3*
Quality of home environment[c]	7.3, *2.0*
Child sex[a]	
Male	51.7%
Female	48.3%
Gestational age (weeks)[a]	38.5, *2.5*
Center-based preschool experience (yes)[d]	56.4%
24 Month cognitive development (T-score)[c]	50.8, *17.2*
Child age at kindergarten (months)[e]	68.2, *7.8*
Child sustained attention (24-months)[c]	4.5, *1.7*

Wave of data collection: [a]Birth certificate; [b]9-months; [c]24-months; [d]preschool; [e]kindergarten.
Source: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Birth Cohort. Selected years 2001–2007.

assure reliability and to calculate the appropriate loading values for deriving our curiosity factor. Standardized scoring of the curiosity factor was conducted, and good internal consistency was demonstrated (α = 0.70, *M* = 0.07, SD = 1.2) (Shah et al., 2021).

Predictors: Relevant multi-level ecological contexts

Neighborhood safety

Neighborhood safety was assessed from parent interviews at 24-months, preschool, and kindergarten timepoint. At the 24-month timepoint parents were asked, "*Do you consider your neighborhood very safe from crime, fairly safe, fairly unsafe or very unsafe?*" At preschool and kindergarten timespoints, parents were asked if they have moved s0e the last timepoint, and if yes, parents were asked again, "*Do you consider your neighborhood very safe from crime, fairly safe, fairly unsafe or very unsafe?*" The description of neighborhood safety from the most recent timepoint was coded as the indicator of "neighborhood safety." Responses were trichotomized (unsafe (combining fairly unsafe and very unsafe responses); fairly safe (ref); very safe).

Parenting quality

Three domains of parenting (Sensitivity, Cognitive Stimulation and Positive Regard) were observed and coded independently during a structured parent-child interaction task (Two-Bags task) at 24-months (NICHD Early Child Care Research Network, 1999; Nord et al., 2006). Both parents and children were instructed to interact for 10 min with two different activities (i.e., pretend play with a set of small dishes and joint book reading). The 10-min parent–child interactions were videotaped and coded. *Parent sensitivity* reflects the degree to which parent interactions are responsive and child centered; *Cognitive Stimulation* reflects a parent's ability to provide effortful teaching to promote language, perceptual and cognitive skills, while being sensitive to the child's developmental level; *Positive regard* reflects a parent's expression of warmth, attentiveness, and attunement. Scores for each domain were rated on a 7-point Likert Scale (1–7) with higher scores demonstrating more positive parenting. Because these three domains of parenting are inter-related, a composite parenting score was calculated as the mean score across the three domains.

Quality of the home environment

The quality of the home environment at 24-months was assessed from an abbreviated version of the HOME Inventory (8-items of the HOME-SF) selected for the ECLS-B (Bradley et al., 2001). The HOME Inventory is an instrument designed to measure the quality and amount of stimulation in the home environment available to the child (Snow et al., 2007), and captured characteristics thought to be important for the promotion and expression of early childhood curiosity. The abbreviated HOME-SF included questions about verbal stimulation and child-directed speech (e.g., *parent spoke spontaneously to child*), parent stimulation of child's play (e.g., *parent provided toys to child*), and safety of the home environment (e.g., *parent kept the child in view*, and *play environment was safe*.) Question items were scored as yes/no, and summed, to generate a cumulative HOME score, with higher scores indicating a more optimal home environment (Range: 1–8).

Enrollment in center-based preschool

Because preschool enrollment can vary by family socioeconomic status and neighborhood characteristics (Guyol et al., 2022), and because early educational environments can foster the expression of curiosity (Jirout et al., 2018), we also included a measure from the preschool timepoint regarding whether the child attended center-based preschool (yes/no).

Socioeconomic status (SES)

We also included a continuous measure of SES from the kindergarten timepoint in our analyses, which was a composite variable calculated by the ECSL-B which included the following components: father's education, mother's education, father's occupation, mother's occupation, and household income. Per the ECLS-B codebook, each individual component was converted to a standardized z-score with a mean of 0 and standard deviation of 1, with the SES composite variable computed as an average of the individual measures (Snow et al., 2009) (Range: −2.31–2.09). Covariates: In our analyses, we included relevant sociodemographic variables. Specifically, we controlled for child sex, maternal age, and marital status (married/unmarried), ascertained from birth certificate data; maternal race/ethnicity, ascertained at 9-months, and child age at the kindergarten timepoint. In addition, because lower developmental skills may be related to the expression of early childhood curiosity, we also included a measure of infant development at 24-months from the Bayley Short-Form Research Edition (BSF-R) as a covariate. The BSF-R was adapted from the Second Edition of the Bayley Scales of Infant Development (Bayley, 1993; NICHD Early Child Care Research Network, 2005), and assessed children's cognitive ability (e.g., language skills, reasoning, problem solving, and memory). Relatedly, because a child's ability to sustain attention with objects is related to the behavioral expression of curiosity (Kidd and Hayden, 2015), we also included a measure of child sustained attention, coded from observations of the child and parent interaction during the Two Bags Task at 24-months. In this task, child behaviors are coded on a scale of 1 (very low) to 7 (very high) and indicate the degree of child sustained attention and involvement with objects, with higher scores indicating higher child-focused attention (Nord et al., 2006).

Analysis

All analyses were conducted using SAS 9.4 (SAS Institute Inc, 2014) (SAS Institute Inc., Cary, NC, USA). Maternal and child characteristics were examined using descriptive statistics. To test the association between relevant proximal and distal ecological contexts and kindergarten curiosity, we performed multivariable linear regression utilizing the SURVEYREG (SAS) procedure. We included relevant socio-demographic characteristics (i.e., child sex, maternal age, marital status, maternal race/ethnicity, child age at the kindergarten timepoint) and covariates related to early childhood curiosity (i.e., cognitive development and sustained attention at 24-months) to adjust for theoretically justified confounds. For our primary analysis (main effects model), we tested the association between parenting quality, home environmental characteristics, enrollment in center-based preschool (*proximal ecological contexts*), level of neighborhood safety (*distal ecological* *context*), and SES (*macro context*) with curiosity at kindergarten. We then tested four moderation models, examining whether the association between neighborhood safety and child curiosity was moderated by (1) parenting quality; (2) quality of the home environment (3) enrollment in center-based preschool and (4) SES. In our moderation analyses, we included the interaction term in the final step of the multivariable regression models. When the interaction was statistically significant ($p < 0.05$), we performed a stratified analysis of the association between the predictor and curiosity, adjusting for the same covariates. Results were reported using standardized regression coefficients (β). In our stratified analyses, we also calculated mean parent-reported curiosity for each level of neighborhood safety (unsafe, fairly safe, very safe). *Post hoc* analyses were conducted to examine pairwise differences in mean-level curiosity between and across neighborhood safety and SES groups. Significant pairwise differences characterized by $p < 0.05$ are indicated in **Figure 1**. Because of the complex sample design, sample weights and the Jackknife method (Wicklin, 2010) were used to account for stratification, clustering and unit non-response, thereby allowing the weighted results to be generalized to the population of U.S. children born in 2001. Per the ECLS-B Codebook, the use of sample weights addresses attrition across waves. The appropriate sample weight was chosen based on the latest timepoint of data collection for the variables in the analytic model, thus accounting for attrition/missing data from earlier timespoints (Snow et al., 2009). In accord with the NCES requirements for ECLS-B data use, reported numbers were rounded to the nearest 50.

Results

Sample characteristics and neighborhood safety characteristics

At the kindergarten timepoint, 4,750 children had data on early childhood curiosity, neighborhood safety data and all covariates, which served as our analytic sample. After applying sample weights, the maternal and child characteristics were generalizable to the US population in 2001. The sample characteristics for the weighted sample, and the timespoints when each demographic variable was ascertained are shown in **Table 1**. Neighborhood safety characteristics at each assessment timepoint are shown in **Table 2**. Across the study timespoints, most families (>50%) reported living in "very safe" neighborhoods.

To address issues of attrition, we compared demographic characteristics of children who were included in our sample (N = 4,750), with children who had curiosity data at kindergarten (N = 6,350), but who were excluded due to missing covariates (N = 1,600). Compared to children who were excluded due to missing data (N = 1,600), children included in our analytic sample were more likely to have White race/ethnicity, be enrolled in center-based preschool, have parents who were married, have higher mental BSF T-scores at 24 months, have higher quality home environments, and have higher socioeconomic status (SES).

Main effects model: Associations of neighborhood safety, parenting quality, home environment, enrollment in center-based preschool, SES and early childhood curiosity

In adjusted models, we found evidence that *proximal* (e.g., parenting quality, quality of the home environment), *distal* (e.g., level of neighborhood safety) and *macro-level* contexts (e.g., SES) were each independently associated with parent-reported curiosity at kindergarten. Regarding the most proximal experiences in the child's home environment, experiencing more positive parenting (β = 0.10, $p < 0.001$) and a higher quality home environment (β = 0.05, p = 0.02) were associated with higher curiosity at kindergarten. Enrollment in center-based preschool was not associated with higher parent-reported curiosity (β = 0.02, p = 0.42). Greater neighborhood safety was also associated greater child curiosity at kindergarten (p = 0.01), but only for children living in "very safe neighborhoods. In our main effects model, children who lived in "very safe" neighborhoods had higher levels of parent-reported curiosity at kindergarten, compared to children who lived in "fairly safe" (ref) neighborhoods, (β = 0.07, p = 0.002). We found no differences in parent-reported curiosity between children who lived in "fairly safe" (ref) versus "unsafe" neighborhoods (β = 0.01, p = 0.42). Regarding macro-level contexts, we found an association between higher SES and higher parent-reported curiosity at kindergarten (β = 0.08, p = 0.003) (**Table 3**).

Test of moderation: Examining whether the association between neighborhood safety and early childhood curiosity is moderated by parenting quality, home environment, center-based preschool attendance, and SES

We tested four moderation models to examine whether the association between neighborhood safety and early childhood curiosity was moderated by factors in the *proximal environment* [(1) parenting, (2) home environment quality, (3) enrollment in center-based preschool]; and the *macro environment* [(4) SES]. The association between neighborhood safety and early childhood curiosity was not moderated by parenting quality (p = 0.50), the quality of the home environment (p = 0.42), or by enrollment in center-based preschool (p = 0.16). We did find evidence that the association between neighborhood safety and early childhood curiosity was moderated by SES (p = 0.008).

Stratified models: Examining the association between neighborhood safety and early childhood curiosity, stratified by SES tertiles

To facilitate a more nuanced examination of the association between the degree of family resource and early childhood curiosity

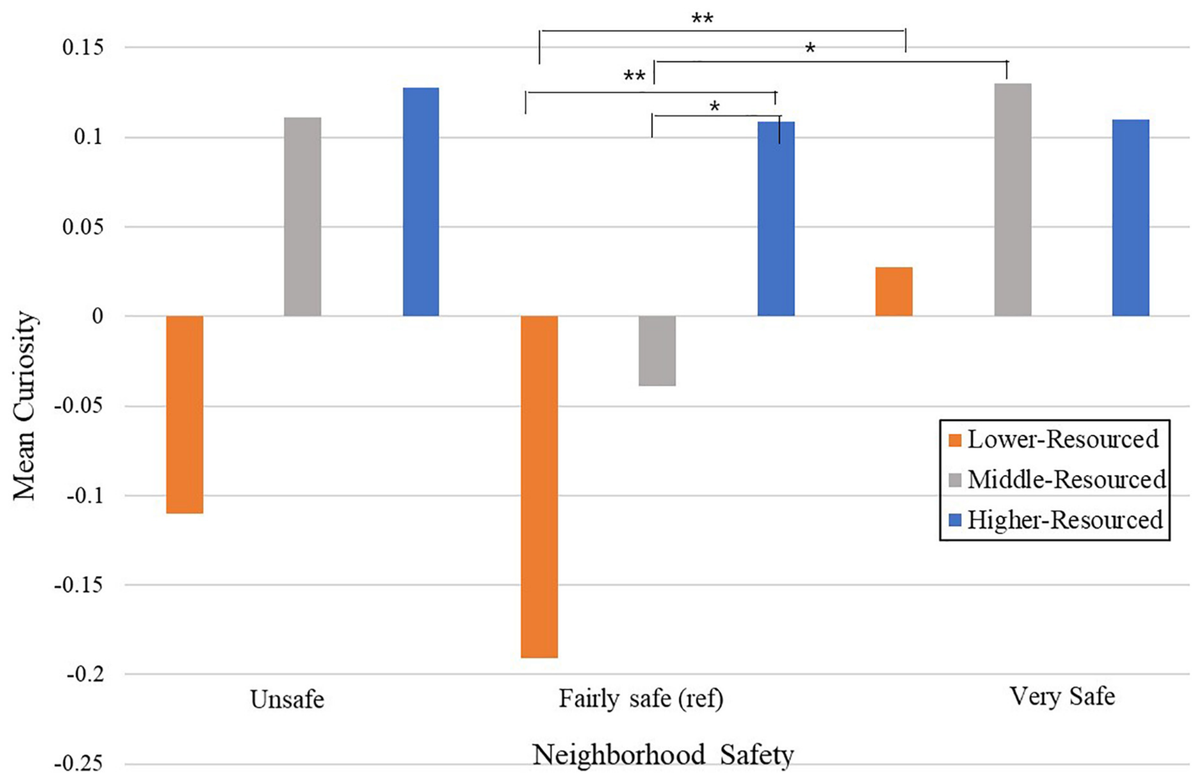

FIGURE 1
Mean parent-reported curiosity at kindergarten, and neighborhood safety, stratified by lower-, middle-, and higher-resourced environments (SES-tertiles). $^{*}p < 0.05$; $^{**}p < 0.01$. Source: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Birth Cohort. Selected years 2001–2007.

across varying levels of neighborhood safety, we stratified by SES tertiles [lower-resourced (lowest SES tertile); middle-resourced (middle SES tertile); higher-resourced (highest SES tertile)]. This allowed us to examine how the association between neighborhood safety and early childhood curiosity varied between lower-, middle-, and higher-resourced families.

For children from *lower-resourced* environments (lowest SES tertile), we found a significant association between the level of neighborhood safety and kindergarten curiosity ($p = 0.03$), but only for lower-resourced children living in "very safe" neighborhoods. Lower-resourced children living in "very safe" neighborhoods demonstrated higher kindergarten curiosity compared with lower-resourced children who lived in "fairly safe" neighborhoods ($\beta = 0.10$, $p = 0.009$), but we found no differences in curiosity between lower-resourced children living in "unsafe" neighborhoods compared to lower-resourced children who lived in "fairly safe" neighborhoods ($\beta = 0.03$, $p = 0.37$). For children from *middle-resourced* environments (middle SES tertile), the level of neighborhood safety was also associated with kindergarten curiosity ($p = 0.045$). Similar to children who lived in lower-resourced environments, middle-resourced children living in "very safe" neighborhoods demonstrated higher kindergarten curiosity compared with middle-resourced children who lived in "fairly safe" neighborhoods ($\beta = 0.10$, $p = 0.01$). We found no differences in curiosity between middle-resourced children living in "unsafe" neighborhoods compared to middle-resourced children who lived in "fairly safe" neighborhoods ($\beta = 0.02$, $p = 0.45$). For children from *higher-resourced* environments (highest SES tertile), the level of neighborhood safety was not associated with kindergarten curiosity ($p = 0.99$). Compared to higher-resourced children who lived in "fairly safe" neighborhoods, neither living in an "unsafe" neighborhood, nor living in a "very safe" neighborhood was associated with kindergarten curiosity ($\beta_{unsafe} = 0.001$, $p = 0.98$; $\beta_{very\ safe} = 0.005$, $p = 0.89$) (Table 4).

We then examined mean levels of curiosity for lower-resourced, middle-resourced, and higher-resourced children, by

TABLE 2 Neighborhood safety (Weighted%) by assessment timepoint.

Neighborhood safety	24 months	Preschool	Kindergarten
Unsafe	7.7%	6.2%	6.9%
Fairly safe (ref)	39.3%	36.1%	33.4%
Very safe	53.0%	57.7%	59.6%

Source: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Birth Cohort. Selected years 2001–2007.

TABLE 3 Adjusted associations of neighborhood safety, parenting quality, home environment, and SES on curiosity (main effects, step 1).

Step 1—Main effects	β (SE)	*P*
Neighborhood safety		
Unsafe	0.01 (0.08)	0.42
Fairly safe (REF)		
Very safe	0.07 (0.04)	0.002
Parenting quality (sensitive, stimulating, positive)	0.10 (0.03)	< 0.001
Home environment quality	0.05 (0.02)	0.02
Attendance at center-based preschool	0.02 (0.04)	0.42
Socioeconomic status	0.08 (0.03)	0.003
Child sustained attention	−0.03 (0.02)	0.21
Maternal age	−0.07 (0.003)	< 0.001
Race/Ethnicity		
Other	0.004 (0.09)	0.76
Asian	−0.02 (0.06)	0.03
Hispanic	0.04 (0.06)	0.13
Black/Non-Hispanic	0.001 (0.05)	0.92
White (Ref)		
24-month cognitive development (Bayley-SFR)	0.17 (0.002)	< 0.001
Child's sex (female)	0.07 (0.03)	< 0.001

β coefficients are standardized betas.
Source: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Birth Cohort. Selected years 2001–2007.

TABLE 4 Adjusted associations of neighborhood safety, parenting, quality of the home environment and curiosity at kindergarten, stratified by socioeconomic status (SES) tertiles.

	Lower-Resourced	Middle-Resourced	Higher-Resourced
Step 2 results (with interaction, stratified by SES tertiles)	β (SE)	β (SE)	β (SE)
Neighborhood safety			
Unsafe	0.03 (0.11)	0.02 (0.17)	0.001 (0.31)
Fairly safe (ref)	–		–
Very safe	0.10 (0.07)**	0.10 (0.07)*	0.005 (0.07)
Quality of home environment	0.06 (0.03)	0.08 (0.03)*	−0.01 (0.04)
Parenting quality (Sensitive/Stimulating/Positive regard)	0.10 (0.04)**	0.09 (0.04)*	0.07 (0.05)
Child sustained attention	0.03 (0.04)	−0.06 (0.04)	−0.07 (0.03)
Cognitive development (24-months)	0.16 (0.004)***	0.15 (0.004)**	0.22 (0.003)***
Race/Ethnicity			
Other	−0.01 (0.16)	0.03 (0.13)	−0.04 (0.19)
Asian	0.006 (0.17)	−0.02 (0.09)	−0.05 (0.07)*
Hispanic	0.002 (0.09)	0.07 (0.10)	0.06 (0.11)
Black/Non-Hispanic	−0.02 (0.07)	0.01 (0.09)	0.03 (0.09)
White (reference)	–	–	–
Mother age	−0.04 (0.005)	−0.05 (0.005)	−0.09 (0.006)*
Child sex (female)	0.03 (0.07)	0.04 (0.07)	0.14 (0.06)***

Covariates included: child sustained attention, 24-month cognitive development, maternal race/ethnicity; maternal age; child sex. β coefficients are standardized betas. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
Source: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Birth Cohort. Selected years 2001–2007.

level of neighborhood safety (**Figure 1**). We found differences for mean -level curiosity *between* neighborhood safety categories (i.e., between fairly safe and very safe neighborhoods), and *within* neighborhood safety categories (i.e., between lower-, middle-, and higher-resourced families living in fairly safe neighborhoods).

Differences in mean curiosity between neighborhood safety categories

We found that mean-level curiosity varied between children living in fairly safe versus very-safe neighborhoods, but only for children who were lower- or -middle resourced. Children from *lower-resourced* environments demonstrated lower mean-level curiosity if they lived in fairly safe versus very-safe environments [$M_{\text{fairly safe}} = -0.19$ versus $M_{\text{very safe}} = 0.03$ ($p = 0.003$)]. Similarly, children from *middle-resourced* environments demonstrated lower mean-level curiosity if they lived in fairly safe versus very-safe environments [$M_{\text{fairly safe}} = -0.04$ versus $M_{\text{very safe}} = 0.13$ ($p = 0.02$)]. There were no differences between mean-level curiosity for lower-resourced or middle-resourced children who lived in "unsafe" versus "fairly safe" neighborhoods ($p_{\text{lower}} = 0.46$ and $p_{\text{middle}} = 0.36$, respectively). For children from higher-resourced environments, mean level curiosity did not vary across neighborhood safety categories (all $p > 0.95$). Of note, lower-resourced children demonstrated curiosity *below the mean* if they lived in "unsafe" and "fairly safe" neighborhoods, but demonstrated curiosity *above the mean* if they lived in a "very safe" neighborhood, with curiosity levels commensurate with children who were from middle-resourced or higher- resourced environments.

Differences in mean curiosity within neighborhood safety categories

For children living in "fairly safe" neighborhoods, mean-level curiosity varied by SES tertile (i.e., between lower-resourced, middle-resourced, higher resourced environments.) We found significant differences in mean curiosity between children from *lower-resourced* and *higher-resourced* environments [$\underline{M}_{\text{lower}} = -0.19$ versus $M_{\text{higher}} = 0.11$ ($p = 0.003$)]. Similarly, we found significant pairwise differences between children from *middle-resourced* and *higher-resourced* environments [$M_{\text{middle}} = -0.04$ versus $M_{\text{higher}} = 0.11$ ($p = 0.03$)]. There were no significant pairwise differences between children from *lower-resourced* and *middle-resourced* environments [$M_{\text{middle}} = -0.19$ versus $M_{\text{middle}} = -0.04$ ($p = 0.07$)]. For children who lived in "unsafe" or "very safe" neighborhoods, mean-level curiosity did not vary across SES tertiles.

Discussion

To our knowledge, this is the first study examining the multi-level ecological contexts associated with early childhood curiosity, including the *proximal* (microsystem) environments characterized by the quality of the early caregiver-child relationship and home environment; the *distal* (mesosystem) environments characterized by the safety of the neighborhood environment and the *macro contexts* (macrosystem) associated with poverty and socio-economic disadvantage. In adjusted, stratified models, our results demonstrated that children from lower-, and middle-resourced environments manifested higher curiosity if they experienced more positive parenting, higher quality home environments, and if they lived in neighborhoods that were "very safe." While we did not find an association between living in "unsafe neighborhoods" and early childhood curiosity across SES categories (lower-, middle-, higher-resourced), we found an association between living in a "very safe" neighborhood (compared with living in a "fairly safe" neighborhood) and higher kindergarten curiosity for lower- and middle-resourced families. This suggests that for less-resourced families, living in a "very safe" neighborhood may be an important, potentially modifiable context to promote a social-emotional process (i.e., curiosity) associated with early academic achievement.

Neighborhood safety and early childhood curiosity

We consider our results in light of the characteristics that underly early childhood curiosity, and consider implications for interventions focused on neighborhood quality and safety. Curiosity is characterized by intrinsic motivation [i.e., *the drive to understand what one does not know* (Hall and Smith, 1903)] and an exploratory drive (e.g., *an exploratory drive to seek novelty* (Berlyne, 1954). In young children, curiosity is largely manifest through expressions of play and exploration (Schulz and Bonawitz, 2007; Cook et al., 2011), and is believed to be influenced by environmental characteristics that either promote or restrict the expression of that exploratory drive. Because a fundamental aspect of curiosity is the ability to engage in exploration, we considered that neighborhoods that were more *unsafe* might be associated with *lower* child exploration (and *lower* levels of *curiosity*), and conversely, that neighborhoods that were *more safe* might be associated with *higher* child exploration (and *higher* levels of *curiosity*).

We found partial support for our hypothesis, but only for children from select *lower-, and middle-resourced* environments. While prior research has suggested that lower neighborhood safety and greater neighborhood poverty are associated with maladaptive child social-emotional outcomes including lower effortful control (Tomlinson et al., 2020), and greater amygdala reactivity to neutral faces (Hyde et al., 2020), and while there is some evidence suggesting that parents who live in unsafe neighborhoods discourage outdoor play and exploration (Dias and Whitaker, 2013), we did not find and association between living in an unsafe neighborhood and lower expressions of curiosity at kindergarten. This may be partially explained by the fact that other, more proximal contexts (e.g., parenting quality and quality of the home environment, described in further detail below) may (independently) support the development of early childhood curiosity, irrespective of the safety of the neighborhood.

While we found no differences in mean-level curiosity between lower-resourced children living in "fairly safe" versus "unsafe" neighborhoods, we observed that lower-resourced children living in "very safe" neighborhoods manifested higher curiosity compared to lower-resourced children who lived in "fairly safe" neighborhoods. Notably, compared to children from higher-resourced environments, children from lower-resourced environments manifested curiosity below the mean if they lived in "fairly safe" environments, but those gaps in early childhood curiosity between lower- and higher-resourced children were eliminated if lower-resourced children lived in "very safe" neighborhoods. Our findings suggest that for lower-income children, living in a "very safe" neighborhood is a potentially modifiable factor which can essentially close the "curiosity gap" observed when lower-resourced children lived in less-safe environments.

Our findings which indicated no differences in curiosity between lower-resourced children living in "unsafe" versus "fairly safe" environments was surprising, for which we offer a possible explanation. We consider that for lower-income children, higher curiosity may be related to a child's ability to play and explore in their neighborhood. For lower-resourced families (i.e., lowest SES tertile), we theorize that this ability to play in their neighborhood is possible only if parents consider their neighborhood to be "very safe." For lower-income families, environments which are considered "unsafe" or even "fairly safe" may still feel "too dangerous" to allow for play and exploration in the neighborhood. Relatedly, it is notable that for higher-resourced families, we found no differences in mean curiosity across neighborhoods ("unsafe," "fairly safe," "very safe"). One possible explanation is that for higher resourced families, children's curiosity is also cultivated through involvement in other activities, rather than predominantly through play and exploration in their neighborhood. There is some evidence to suggest that irrespective of neighborhood characteristics, more resourced families are more likely to enroll their children in recreational activities to foster child engagement, compared to less-resourced families (Galaviz et al., 2016). Taken together, this suggests that while higher-SES families may have resources to access supplemental activities which may foster curiosity, lower-SES families may have less access to these opportunities, which makes the context of neighborhood safety, and the possibilities for play and exploration within their neighborhood, an especially relevant context for the promotion of curiosity.

Neighborhood spaces as a modifiable ecological context to foster play and curiosity

As children grow, they spend more time in the neighborhood, which becomes a salient ecological context for play, exploration and learning. Some neighborhood characteristics, described by the quality of the built environment (Pearl et al., 2001; Davison and Lawson, 2006) appear to be especially salient to child development, and include the physical properties of the neighborhood such as the presence of outdoor play spaces, and the ability to engage in them safely. There is research to support the benefits of designing everyday neighborhood spaces like bus stops, libraries and supermarkets in ways that are promotive of play, exploration and learning (Hassinger-Das et al., 2018, 2020, 2021; Schlesinger and Hirsh-Pasek, 2019).

Playful Learning Landscapes (PLL), for example, evolved as a collaboration between researchers at the Playful Learning Landscape Action Network and the Brookings Institute, with the aim of transforming spaces where families wait (e.g., bus stops, supermarkets and laundromats) into hubs that could promote academic and social enrichment, (Hassinger-Das et al., 2018, 2021). Urban Thinkscape, one example of a playful learning landscapes evolved as a collaboration between local community leaders in Philadelphia and child development researchers, with the aim of "marrying" architectural design with the science of learning by creating a playground installation to foster caregiver-child conversations around topics foundational to school readiness. The location for Urban Thinkscape was selected based on 3 criteria: (1) >50% residents living below the poverty line; (2) geographic areas in need of accessible play spaces; and (3) presence of community organizations. Working with community members, the researchers melded neighborhood values with the science of how and what children learn and literally worked these into the built environment. For example, a lot on which Martin Luther King delivered one of the Freedom March speeches was chosen as the designated space. Large rotating puzzles along with installations sparking inhibition control and shape identification dotted the new space where people waited to board a city bus. Results demonstrated that local spaces could be crafted into socially interactive spaces designed to scaffold and support children's early learning experiences in language, literacy and STEM skills (Hassinger-Das et al., 2020).

The mechanism by which projects such as "Playful Learning Landscapes" and "Urban Thinkscape" is thought to promote early learning is by enhancing opportunities for social interaction and conversational exchanges between parents and young children (Schlesinger and Hirsh-Pasek, 2019). Prior research demonstrates that that socioeconomically disadvantaged children preferentially benefit from greater child-directed speech and conversational exchanges (Zimmerman et al., 2009; Vernon-Feagans et al., 2013; Hirsh-Pasek et al., 2015a; Pace et al., 2017), and that children learn best in environments that are *interactive*, which encourage *turn-taking*, *active engagement, dialogic exchanges*, and *intrinsically motivated questions* (Zimmerman et al., 2009; Hirsh-Pasek et al., 2015a, b). There is evidence suggesting that initiatives which transform neighborhood environments into safe, playful learning spaces, promote caregiver-child interaction and interactive discourse, contributing to active and engaged child learning (Hassinger-Das et al., 2020).

We theorize that these same "built environments," especially in disadvantaged communities, can foster *early childhood curiosity* by creating interactive opportunities to engage in conversational exchanges that are dotted with questions (Gaudreau et al., 2021). Our previous research found an association between more frequent parent conversation (during share television viewing) and higher kindergarten curiosity, with a greater magnitude of association in children from low-SES families (Shah et al., 2021). Research from Playful Learning Landscapes including Urban Thinkscape and other projects like Parkopolis (Bustamante et al., 2020); a life-sized human board game) and Fractionball (Bustamante et al., 2022); a recrafted basketball court designed to promote fraction talk) demonstrate that transforming neighborhood spaces into areas which prioritize caregiver-child interactions, facilitate language-learning opportunities which are promotive of school readiness (Hassinger-Das et al., 2018) and question asking–a behavior associated with curiosity. Transforming neighborhoods into safer, more playful spaces can also lead to the promotion of early childhood *curiosity* by cultivating opportunities to engage in back and forth pedagogical exchanges, (e.g., "*Look at this!"; "What does that mean?"; How does it work?"; "Why does it do that?*").

Proximal contexts to promote early childhood curiosity: The role of positive parenting and quality home environments

In addition to the distal ecological context of the safety of the neighborhood environment, our results also support the importance of the quality of the proximal caregiving environment for the expression of early childhood curiosity. For children from lower and middle-resourced environments, they demonstrated higher curiosity if they experienced more positive parenting (manifest as more sensitive, stimulating, and attuned parenting), and, for middle-resourced children, if they experienced higher quality home environments (manifest by higher safety, supervision, and stimulation). Curiosity is manifest by exploratory behavior that is intrinsically motivated (Kashdan and Silvia, 2009). The expression of curiosity is enhanced when individuals are allowed to engage in activities that are align with their idiosyncratic interests (Black and Deci, 2000), however, for young children, they require the support and scaffolding of their caregivers to effectively engage with their environment (Sameroff, 1975). Attachment theory considers that children who experience more sensitive and scaffolding parenting in infancy are more likely to have secure attachment, manifest by greater secure-base exploration (Bowlby, 1969; Ainsworth et al., 1978). Sensitive, scaffolding parenting has been shown to be promotive of numerous adaptive social-emotional processes including self-regulation (Calkins, 2011), effortful control (Regueiro et al., 2020), and executive function (Valcan et al., 2018). Our results similarly suggest that sensitive, scaffolding, positive parenting is also promotive of early childhood curiosity, with a greater magnitude of association for lower-income children.

Cumulative risk models also demonstrate how environments of socio-economic disadvantage, in combination with low-quality home environments are detrimental to young children's social-emotional development (Watamura et al., 2011). Disadvantaged home environments characterized by low environmental quality (i.e., lower home learning experiences) and less positive parenting practices have been linked with less optimal social-emotional outcomes (Foster et al., 2005), including lower self-regulation (Raikes et al., 2007). However, the converse has also been shown: for low income children, more stimulating home environments, and more sensitive, scaffolding parenting have also been associated with higher academic achievement, and lower child behavior problems (Longo et al., 2017). Our findings, demonstrating an association between more positive parenting, higher quality home environments and higher curiosity at kindergarten similarly align with a growing body of evidence highlighting the importance of the quality of early caregiving to foster more adaptive social-emotional outcomes in lower-income children.

We consider our results in consideration of the factors that are believed to foster curiosity. Young children have an intrinsic desire to explore and make sense of the world around them (Piaget, 1926), and environments which foster exploration, discovery and pedagogical inquiry are thought to promote the expression of curiosity (Jirout, 2020). In school-age children, parents who ask questions that align with their children's interests, and who provide exposure to new experiences, and encouragement to seek new knowledge, have children who were rated higher in scientific curiosity in middle childhood (Gottfried et al., 2016). For *young children*, our results suggest that similar conditions are also promotive of curiosity, including *greater child-directed conversation* (e.g., the parent talks more to the child, and encourages pedagogical exchanges); *safe, stimulating home environments* (e.g., parent provides adequate supervision, offers toys for exploratory play); and *sensitive and scaffolding parenting interactions* (e.g., parent is attuned to the child's idiosyncratic interests, and demonstrates sensitive support in dyadic interactions).

Limitations

Our study had several strengths and limitations. Strengths include the use of a nationally representative sample which included (1) child behavioral data (from which we could derive a measure of curiosity), (2) measures of multi-level ecological contexts salient to child development and (3) data from 9 months to kindergarten. One limitation is that our curiosity factor was derived from a single parent-report behavioral measure at the kindergarten timepoint. As such, we acknowledge the potential bias and shared method variance associated with parent report measures. In addition, our measure of neighborhood safety was based on a parent-report questionnaire, and additional objective details about neighborhood characteristics including levels of poverty, violence and other community characteristics were not available. Relatedly, another limitation relates to the lack of clarity on the measurement of environmental safety among lower-, middle-, and higher-resourced families. In addition, with SES divided into tertiles, small sample sizes for some groups, (e.g., few higher-resourced families lived in "unsafe" neighborhoods), likely contributed to a lack of statistical significance in pairwise comparisons (e.g., between lower-resourced. middle-resourced, and higher-resourced children in "unsafe" environments). Relatedly, while the magnitude of association between neighborhood safety and curiosity across SES categories was significant, these associations were on the lower side of the effect size. However, given that our results are drawn from a nationally representative sample, at a population level, even small effect sizes are impactful for population-making decisions. In addition, we acknowledge the limitation that some participants were not included in the final sample due to attrition or missing data. Finally, while the ECLS-B is a rich dataset and among the few longitudinal cohorts from the United States, the dataset did not include outcomes beyond the kindergarten timepoint. Future research should consider the association between early childhood curiosity and outcomes throughout the childhood lifespan, (Kashdan et al., 2013b), and should examine the pathways through which cultivation of neighborhood spaces may foster curiosity and help mitigate the poverty achievement gap (Grogan-Kaylor and Woolley, 2010). Despite these limitations, we believe that our results have some important implications for caregivers, pediatricians and policymakers.

Implications and conclusion

Building on our previous work which identified an association between higher early childhood curiosity and higher academic achievement, with a greater magnitude of effect in low-income children (Shah et al., 2018), we identified several ecological contexts in early childhood (i.e., the proximal contexts of the home environment and parenting quality and the distal context of neighborhood safety) associated with higher curiosity in under-resourced children. Our results identify several areas that can serve as potential targets of intervention to foster early childhood curiosity. Environments which support scaffolded exploration, questioning, and discovery has been shown to promote early learning (Hirsh-Pasek et al., 2015b). Thus, interventions which target parent scaffolding and promote opportunities for conversational exchanges, may be similarly beneficial for the cultivation of curiosity, especially in lower-resourced children (Hirsh-Pasek et al., 2015a). We also found that higher neighborhood safety (i.e., living in a "very safe" neighborhood) was associated with higher early childhood curiosity in lower-income children. Novel community-based partnerships in under-resourced communities have demonstrated that transforming neighborhood spaces into areas which prioritize caregiver-child interactions fosters language-learning opportunities which are promotive of early learning (Hassinger-Das et al., 2018). We believe that such interventions which transform neighborhoods into safer, more playful spaces (especially in lower-resourced environments), may also lead to the promotion of early childhood curiosity. Future research should consider the mechanisms and pathways by which safe neighborhoods foster early childhood curiosity, especially for families with socioeconomic disadvantage.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: Data can be accessed after entering into a data-use agreement with the Institute of Educational Statistics, National Center for Educational Statistics.

Author contributions

All authors have participated in the concept, design, analysis or interpretation of data, and have assisted with the drafting or revising of the manuscript and responsible for the reported research, and have approved the manuscript as submitted.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix

TABLE A1 Derived curiosity factor from the ECLS-B.

Question Items in Derived Curiosity Factor	Loading Coefficient
Likes to try new things	0.71
Shows imagination in work and play	0.58
Shows eagerness to learn new things	0.59
Easily adjusts to a new situation	0.56

Cronbach's alpha: $\alpha = 0.70$.
Adjusted GFI = 0.91.
Standardized RMR (SRMR) = 0.047.
Source: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Birth Cohort. Selected years 2001–2007.

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EDITED BY
Brett Miller,
National Institutes of Health (NIH),
United States

REVIEWED BY
Molly McCarthy,
Monash University, Australia
Yanhua Xu,
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Caitlin Canfield,
Grossman School of Medicine,
New York University, United States
Elizabeth Connors,
Yale University, United States
Paige Greenwood,
Columbia University Irving Medical Center,
United States

*CORRESPONDENCE
Elena L. Grigorenko
✉ elena.grigorenko@times.uh.edu

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Impact of the COVID-19 pandemic on youth delinquency: A discontinuous growth analysis

Nan Li[1], Diana Quintana[2], Matthew Shelton[2] and Elena L. Grigorenko[1,3]*

[1]Department of Psychology, University of Houston, Houston, TX, United States, [2]Harris County Juvenile Probation Department, Houston, TX, United States, [3]Department of Molecular and Human Genetics, Baylor College of Medicine, Houston, TX, United States

Introduction: This study aimed to investigate (a) the immediate and long-term changes in youth offending rates among 138 neighborhoods within a large metropolitan area in the context of COVID-19 and (b) the extent to which the socioeconomic composition of the neighborhoods accounted for variations of the changes.

Methods: Discontinuous growth models were applied to demonstrate the changes in offenses against a person, property offenses, and drug-related offenses one-year prior to, at (March 2020), and one-year following the pandemic.

Results: At the onset of the pandemic, we registered an immediate reduction in offenses against a person and property offenses but not in drug-related offenses. There was a steeper declining trend for property offenses one-year following the pandemic as compared with that one-year prior to the pandemic. The neighborhood concentration of affluence and poverty was not related to the immediate reduction in any type of delinquency.

Discussion: We conclude that the COVID-19 pandemic not only had an abrupt but also an enduring impact on youth delinquency.

KEYWORDS

COVID-19, school closures, discontinuous growth model, delinquency, SES

Introduction

In response to the COVID-19 pandemic, national and local authorities around the world implemented a variety of social restriction policies in order to curb the spread of the virus and keep their populations safe (Hodgkinson et al., 2022). Collectively referred to as “containment measures,” various social restrictions were designed to limit the transmission of the virus between individuals, usually involving some combination of stay-at-home orders, social distancing, travel bans, closures of schools, non-essential businesses, restaurants, and theaters, and barring public and private gatherings (Nivette et al., 2021; Payne et al., 2022). This unprecedented implementation of social restrictions has been considered “the largest criminological experiment in history” (Stickle and Felson, 2020, p. 525), which has led to a burgeoning body of research on the relationship between the COVID-19 pandemic and crime (e.g., Felson et al., 2020; Mohler et al., 2020; Nivette et al., 2021).

Nevertheless, existing studies are limited in several ways despite their high significance. First, the vast majority of studies have focused on the change in recorded crime in the context of the COVID-19 pandemic among adults. Less is known about the association between the pandemic and delinquency among youth (for exceptions, see McCarthy et al., 2021; Revital and Haviv, 2022). School closures and remote instruction that are unique containment measures for youth disrupted their routine activities. In turn, this disruption exerted a profound impact on youth delinquency.

Second, given the acute nature of the COVID-19 pandemic, nearly all existing research has been concentrated on the abrupt change of offending following the pandemic (i.e., whether the observed offending rates deviated from what one would have expected in the absence of the COVID-19 pandemic). From a developmental/life course criminology perspective, however, turning points, such as the pandemic, are not only presumed to stimulate an immediate but also a long-term change (Laub and Sampson, 1993). Yet, the enduring impact of the COVID-19 pandemic on offending has not drawn sufficient attention in the existing literature.

Third, despite the recognition of the heterogeneity of the relationship between COVID-19 and offending across communities (Campedelli et al., 2020; McCarthy et al., 2021; Andresen and Hodgkinson, 2022; Hodgkinson et al., 2022), contextual factors associated with such variation are understudied. This is because the units of analyses in existing research have overwhelmingly been cities (e.g., Mohler et al., 2020; Nivette et al., 2021) or countries (e.g., Gerell et al., 2020; Halford et al., 2020). However, focusing on crime change at the macro level precludes identifying "local" contextual factors that may exacerbate or mitigate the impact of the pandemic on crime and delinquent behavior.

The present study aimed to (a) evaluate the abrupt (the immediate change of offending in the month when containment measures were implemented) and long-term (developmental trajectory of offending 1 year following the implementation of containment measures relative to that 1 year prior to the pandemic) changes in youth offending rates in the context of the COVID-19 pandemic and (b) investigate the extent to which the socioeconomic composition of neighborhoods accounted for variations in the immediate and long-term changes in youth offending rates. Specifically, we employed discontinuous growth models (DGM) to evaluate changes of youth offending rates in offenses against a person, property offenses, and drug-related offenses among 138 neighborhoods in Harris County, Houston, Texas, from March 2019 to February 2021 and explored the extent to which the concentration of affluence and poverty accounted for neighborhood variations of youth offending changes prior to, at, and following the implementation of containment measures in response to the pandemic.

The abrupt change of offending following the COVID-19 pandemic

Implementing various containment measures, such as stay-at-home orders, drastically disrupted routine activities, which in turn had a spillover effect on the structural opportunity for crime and delinquency. The routine activity theory has been the dominant theory in understanding the relationship between the COVID-19 pandemic and offending. In their theory development, Cohen and Felson (1979) posited that structural changes in routine activity patterns could impact crime rate trends by affecting the concurrence in space and time of three elements—motivated offenders, suitable targets, and the absence of guardians against a violation. They further argued that the lack of any one of these elements is sufficient to prevent the successful completion of committing a crime.

An array of recent research has demonstrated that the impact of the structural change of routine activities on the change of offending in the context of COVID-19 varies as a function of crime types, locations, and time frames. In general, while a significant reduction of offending counts in shoplifting, theft, and theft from a vehicle following the pandemic has consistently been observed across different regions (Ashby, 2020; Halford et al., 2020; Hodgkinson and Andresen, 2020; Campedelli et al., 2021; Langton et al., 2021; Nivette et al., 2021; Payne et al., 2021; Koppel et al., 2022), findings for other types of crime are mixed. Specifically, (a) some studies have reported no change in assault (Ashby, 2020; Hodgkinson and Andresen, 2020; Mohler et al., 2020; Campedelli et al., 2021; Payne et al., 2022), whereas other studies have reported a significant reduction in assault (Gerell et al., 2020; Halford et al., 2020; Langton et al., 2021; Nivette et al., 2021; Koppel et al., 2022); (b) some studies have reported a significant reduction in residential burglary (Ashby, 2020; Halford et al., 2020; Payne et al., 2021; Koppel et al., 2022), whereas other studies have reported an increase in commercial burglary (Hodgkinson and Andresen, 2020; Koppel et al., 2022); and (c) some studies have reported no change in robbery (Gerell et al., 2020; Mohler et al., 2020), whereas other studies have reported a significant reduction in robbery (Campedelli et al., 2021; Langton et al., 2021; Nivette et al., 2021; Koppel et al., 2022).

Despite noticeable variations, existing findings largely supported the notion that the controlled closure (e.g., stay-at-home restrictions) and limited social interactions (e.g., cancelations of private and public gatherings) influenced criminal opportunities by increasing the guardianship and reducing the exposure of victims to motivated offenders, which in turn resulted in the abrupt change of offending (Stickle and Felson, 2020). It is important to note that the aforementioned studies all revolve around recorded crime data for adults. Research on the situational explanation of individual deviant behavior suggests that containment measures, particularly school closures, and remote instruction, may have had a profound effect on the developmental patterns of delinquency for youth (Buchanan et al., 2020; McCarthy et al., 2021). This assumption has been evidenced by two studies.

McCarthy et al. (2021) examined changes in reported offending by youth aged 10–17 years old in Queensland, Australia, between periods prior to (January 1, 2018–March 31, 2020) and following (April 1, 2020–June 30, 2020) the introduction of containment measures. Results of Poisson panel analysis with random intercept showed significant decreases in rates of offenses against a person, property offenses, and public order offenses, but not drug-related offenses, following restrictions to movement and gathering as compared to the pre-COVID-19 period. Revital and Haviv (2022) used data on weekly juvenile crime files obtained from Israel Police between January 2019 and December 2020 to explore whether the crime time series changed significantly following the two lockdown periods (March 25–May 4 of 2020 and September 25–October 17 of 2020). Results of autoregressive integrated moving average (ARIMA) models showed a significant reduction in assaults during lockdowns and in drug-related offenses during the COVID-19 pandemic but no significant alteration in robbery and property offenses. The two studies presented inconsistent findings, challenging the generalizability regarding the impact of COVID-19 on youth offending. Thus, additional research is needed to provide a better understanding of this issue. Moreover, the statistical approaches employed by the two aforementioned studies pertaining to youth, and the vast majority of studies for adults, successfully reflected the overall discrepancy between prior to and following the pandemic but failed to represent the dynamic nature of change of offending during the post-transition period. In other words, there is sufficient knowledge about the abrupt impact of the COVID-19 pandemic on offending, but little is known about its enduring impact.

The long-term change of offending following the COVID-19 pandemic

Routine activity theory provides a situational explanation in terms of when and where crime is more likely to occur (Cohen and Felson, 1979), emphasizing the immediate change of crime and delinquent behavior at the onset of the COVID-19 pandemic. Importantly, such an event as the pandemic is not only discrete but also "bounded in time and space" (Morgeson et al., 2015, p. 516). According to the events system theory (EST; Morgeson et al., 2015), COVID-19 stimulated larger chains of subsequent events that affected individual and collective behavior across time. For example, COVID-19 led to school closures and then remote instruction, which in turn caused more interactions between parents and children. These growing interactions could have either strengthened or weakened the bonds of parents with their children (Prime et al., 2020). The strengthened bonds could prohibit delinquency, whereas the weakened bonds could increase delinquency (Hirschi, 1969). This process is presumed to occur in an incremental and gradual manner. Toward this end, the pandemic not only exerted an abrupt but also an enduring impact on offending. In fact, recognizing the abrupt and enduring impact of an event on the change of criminal trajectories is not new (Bersani and Doherty, 2013). From a developmental/life course criminology perspective, for example, turning points such as marriage are so critical for some individuals that they immediately redirect their criminal trajectories, but less so for many others, who instead decrease their offenses gradually through an incremental process (Laub and Sampson, 1993). The long-term change in crime and delinquency in the context of the COVID-19 pandemic has been understudied. In other words, little is known about the developmental trajectory of delinquency following the implementation of containment measures.

Contextual factors and offending during the COVID-19 pandemic

Beyond knowing the extent to which implemented containment measures related to COVID-19 has had effects on the change of offending, a better understanding of contextual factors that may exacerbate or mitigate the disparity of crime trajectories has practical implications. Social disorganization theory serves as a well-accepted theoretical perspective in understanding neighborhood crime (Shaw and McKay, 1942; Kornhauser, 1978; Bursik, 1988; Sampson and Groves, 1989). The theory posits that structural characteristics of neighborhoods—poverty, racial/ethnic heterogeneity, and residential mobility—lead to decreased formal and informal social control, which in turn increases the risk of offending and delinquency.

A growing number of studies have examined the extent to which various structural characteristics contribute to the change of different crime types following the implementation of containment measures (Campedelli et al., 2020; McCarthy et al., 2021; Andresen and Hodgkinson, 2022; Hodgkinson et al., 2022). In general, prior research suggests that the impact of a specific contextual feature on the change of offending depends on offending types. Yet, contradictory findings have also emerged in prior research. In a study based on 77 communities in Chicago, Campedelli et al. (2020) demonstrated that a higher level of poverty was related to a lower likelihood of reduction of burglary as compared to no change or increase, but it had no effect on assault, narcotics, and robbery reduction. In another study based on 362 dissemination areas (i.e., small, relatively stable geographic units composed of one or more dissemination blocks; each block includes 400–700 persons and represents the smallest standard geographic area for which all census data are disseminated) in Saskatoon, Canada, Hodgkinson et al. (2022) registered that areas with higher median family income were more likely to experience no change in commercial burglary, residential burglary, theft of a vehicle, violence, and mischief than experiencing decreases in those crime types during the COVID-19 lockdown. McCarthy et al. (2021) focused on youth offending rates in Queensland, Australia, and observed that containment measures stimulated notably steeper declines in property and public order offenses (but not in offenses against a person or drug-related offenses) in communities with lower than higher socioeconomic status (SES).

Notwithstanding the variations of the three studies in design, units of analysis, and analytical methods, the findings of Campedelli et al. (2020) showed that a higher level of community SES was associated with a higher likelihood of a reduction in crime. In contrast, the findings of Hodgkinson et al. (2022) and McCarthy et al. (2021) showed that a lower level of community SES was related to a higher likelihood of a reduction in crime and delinquency. These inconsistent findings warrant additional research into the effect of community characteristics on crime trajectories during the COVID-19 pandemic.

The current study

Despite substantial efforts devoted to understanding the relationship between the COVID-19 pandemic and offending for adults, less is known about such a phenomenon for youth as there are only limited relevant studies (McCarthy et al., 2021; Revital and Haviv, 2022). The present study aimed to fill in the gaps by (a) investigating the immediate and long-term change in youth offending rates for three types of offenses—offenses against a person, property offenses, and drug-related offenses—among 138 neighborhoods in Harris County, Houston, Texas in the context of COVID-19 and (b) evaluating the extent to which the socioeconomic composition of neighborhoods as indexed by concentrated affluence and poverty accounted for variations of the change of youth offending rates.

Methodologically, the current study features a novel application of the discontinuous growth models, DGM, under the multilevel modeling (MLM) framework to capture the dynamic change of youth offending rates prior to (March 2019–February 2020), at (March 2020), and following (March 2020–February 2021) the implementation of containment measures. Time series analysis and its extensions, the method dominantly employed in existing research related to COVID-19 and crime, address the abrupt change due to the pandemic. However, DGM allows for (a) an evaluation of the trajectory in offending rates prior to the pandemic (i.e., pre-transition slope), (b) determining the extent to which the pandemic produces an immediate change in the offending rates relative to what would have been expected from the pre-transition trajectory (i.e., transition), and (c) comparing the pre-transition trajectory with post-transition trajectory (Bliese et al., 2017). Akin to a one-group pretest-posttest design, modeling the pre-transition slope is essential to establish the baseline and characterize the pretest effect. The transition parameter captures the abrupt impact of the pandemic on offending rates. A contrast between the pre-transition slope and the post-transition slope allows for the evaluation of the enduring impact of the COVID-19 pandemic on youth offending trajectories. The MLM framework takes the dependency (i.e., occasions are nested within neighborhoods) into account while modeling the changes and allows for the investigation of the contextual factors associated with the changes.

Past research has suggested that pleasant temperatures tend to prompt individuals to spend more time outside the home, which increases opportunities for victimization (Hipp et al., 2004). Thus, seasonality is a confounder that needs to be considered while investigating delinquency trends over time (McCarthy et al., 2021). After taking seasonal variations into account, we hypothesized that (a) there would be no systematic change in offenses against a person and property offenses across the 12 months prior to the pandemic, whereas a decreasing trend would be expected for drug-related offenses due to a new policy that Harris County had stopped prosecuting some marijuana possession cases since July 2019 (HPM Digital Team, 2019); (b) in line with McCarthy et al. (2021) there would be an immediate reduction in offenses against a person and property offenses, but no change for drug-related offenses in March 2020; (c) given the lack of empirical evidence regarding the developmental trajectory of offending following the pandemic, we did not offer specific hypotheses for the post-transition slope; yet, we completed a relative explorative study; and (d) the concentration of affluence and poverty would account for neighborhood variations of these pandemic-related changes.

Methods

Data sources

Two data sources were exploited to perform the analyses. Youth delinquency data were provided by Harris County Juvenile Probation Department (HCJPD), Houston, Texas, including all reported delinquent incidents by youth aged 10–17 years that occurred in Harris County from January 2006 to March 2021. For the present study, a subset of offending types was selected, including offenses against a person, property offenses, and drug-related offenses that occurred between March 1, 2019, and February 28, 2021. Offenses against a person include assault, aggravated robbery, robbery, and murder. Property offenses include unauthorized use of a motor vehicle, theft, and burglary. Drug-related offenses include possession or use of illicit drugs. Selecting such a time frame allows the proposed models to capture the dynamic change 1 year prior to and 1 year following the implementation of containment measures.

Harris County is located in greater Houston, Texas, the fourth-largest metropolitan area in the United States (U.S.). The county's population was 4.73 million, according to the 2021 census (U.S. Census Bureau, 2021). Similar to many other counties in the state, Harris County initially implemented strict containment measures pertaining to schools and non-essential businesses in response to the pandemic and gradually loosened the social restrictions, with schools being to open among the last entities. Governor of Texas, Greg Abbott, issued a disaster proclamation on March 13, 2020, in response to the imminent threat of COVID-19 to all counties in the state of Texas (Exec. Order GA 08, 2020). Schools in the state were ordered to close on March 19, 2020, and remained temporarily closed for the 2019–2020 school year (Exec. Order GA 16, 2020). Students in the Houston Independent School District (HISD), including nearly all youth involved in the current study, began the 2020–2021 school year virtually on September 8, 2020, and continued with remote learning for 6 weeks through October 16, 2020. Starting October 19, 2020, parents had the option to choose remote instruction for the fall semester (through January 29, 2021) or the entire school year (through June 11, 2021) or face-to-face instructions for the entire school year (HISD, 2021). Therefore, youth involved in the current study were influenced by school closures and remote instruction during the 1 year follow-up since the proclamation of the pandemic.

The second data source was the American Community Survey (2015–2019 estimates). This survey provides socioeconomic data from stable geographic units defined by the U.S. Census Bureau designed to reflect U.S. Postal Service zip code boundaries.

Measurement

The dependent variable was the monthly count of youth delinquency recorded by HCJPD within each zip code during the study period. Zip codes were the smallest geographic unit provided in the data. Table 1 presents descriptive statistics of the aggregate offending counts over the 2-year follow-up period for offenses against a person, property offenses, and drug-related offenses based on the 138 neighborhoods involved in the analyses. Figure 1 shows the change of the average observed counts of delinquency across 138 neighborhoods. Youth population is a measure that taps into neighborhood variation in the number of youths between the ages of 10 and 19 (*mdn* = 4,906, *min* = 607, *max* = 22,508).

We used the Index of Concentration at the Extremes (ICE) to measure the concentration of affluence and poverty (Krieger et al., 2016). We used the formula ICE = (A − P)/T, where A, P, and T reflect the number of people in each neighborhood belonging to the most privileged group, the least privileged group, and the total population, respectively. Theoretically, ICE scores can range from −1.0 (absolute concentrated poverty) to 1.0 (absolute concentrated affluence), with a 0 indicating that a given neighborhood comprised equally affluent and

TABLE 1 Descriptive statistics of monthly offending counts for offenses against a person, property offenses, and drug-related offenses across 138 neighborhoods.

Offense type	*M*	*SD*	*Mdn*	*Min*	*Max*
Offenses against a person	19.28	15.26	16.50	0	62
Property offenses	13.29	10.75	11.00	0	54
Drug-related offenses	4.17	3.84	3.00	0	18

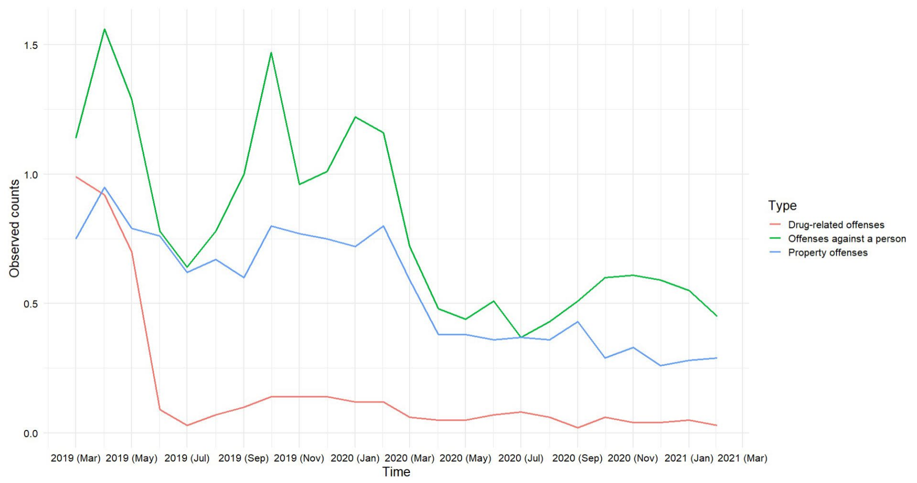

FIGURE 1
Longitudinal change of average observed counts of delinquency (*N* =138).

disadvantaged families. We computed ICE as follows: White, non-Hispanic households with incomes of $100,000 or greater (most privileged) compared to non-White or Hispanic households with incomes of $24,999 or less (least privileged). This race-income measure avoids collinearity problems that arise from including separate measures for each separate component in a single model. The ICE scores ranged from −0.351 to 0.538 ($M = 0.045$, $SD = 0.224$) in our sample of 138 neighborhoods.

In order to account for the seasonal effects on the likelihood of youth offending, the average monthly temperature was included as a time-varying covariate (Hipp et al., 2004). Historical temperature data were extracted from Weather Underground (n.d.). To facilitate interpretation, the average monthly temperature was centered at the grand mean ($M = 71.79$, $SD = 10.98$).

Analyses

DGM is an extension of the linear growth model where change is described using a discontinuous trajectory with separate slopes through distinct phases of time (Hoffman, 2015). The discontinuity can be achieved through recoding time variables (Bliese et al., 2017). Table 2 shows the coding for time variables involved in the DGM. The first time-varying predictor (TIME) represented the linear change across the 24 months and was centered in March 2019, which was 1 year prior to the occurrence of COVID-19. The second time-varying predictor captures the intercept discontinuity (INTDIS), which was coded 0 prior to the onset of the pandemic (i.e., March 2019–February 2020) and 1 after the onset of the pandemic (i.e., March 2020–February 2021). The third time-varying variable represents the slope discontinuity (SLOPEDIS), which was coded 0 prior to or during the pandemic and coded using consecutive integer values from 0 to 11 for TIMEs 12–23. The three aforementioned time-varying variables, along with seasonality, were identical for all neighborhoods involved in the analyses.

Given the number of aggregate neighborhood delinquency naturally occurring as frequency counts, DGM was estimated under the multilevel generalized linear mixed models (ML-GLMM) framework. The selection of ML-GLMM for a count variable depends on the assumptions of the count response distribution (i.e., underdispersion, equidispersion, and overdispersion). Peugh et al.

TABLE 2 Coding of time variables.

Year	Month	TIME	INTDIS	SLOPEDIS
2019	March	0	0	0
2019	April	1	0	0
2019	May	2	0	0
2019	June	3	0	0
2019	July	4	0	0
2019	August	5	0	0
2019	September	6	0	0
2019	October	7	0	0
2019	November	8	0	0
2019	December	9	0	0
2020	January	10	0	0
2020	February	11	0	0
2020	March	12	1	0
2020	April	13	1	1
2020	May	14	1	2
2020	June	15	1	3
2020	July	16	1	4
2020	August	17	1	5
2020	September	18	1	6
2020	October	19	1	7
2020	November	20	1	8
2020	December	21	1	9
2021	January	22	1	10
2021	February	23	1	11

TIME represents the linear change across the 24 months, INTDIS represents the intercept discontinuity, and SLOPEDIS represents the slope discontinuity.

(2021) recommended identifying the best-fitting ML-GLMM by comparing six different models: Poisson, random intercept Poisson (RIP), negative binomial (NB), zero-inflated Poisson (ZIP), zero-inflated random intercept Poisson (ZI-RIP), and zero-inflated negative binomial (ZI-NB) models. Equations 1–3 represent models sampling count response values for Poisson, RIP, and NB, respectively. Adding Equation 4, a binary logistic regression, to the aforementioned count models (Equations 1–3) led to ZIP, ZI-RIP, and ZI-NB, respectively:

$$\log(Y_{ti}) = \gamma_{00} + \gamma_{10}(TIME_{ti}) + \gamma_{20}(INTDIS_{ti}) + \gamma_{30}(SLOPEDIS_{ti}) + \gamma_{40}(Season_{ti}) + u_{1i}(TIME_{ti}) + u_{2i}(INTDIS_{ti}) + u_{3i}(SLOPEDIS_{ti}) + \log(P_i) \quad (1)$$

$$\log(Y_{ti}) = \gamma_{00} + \gamma_{10}(TIME_{ti}) + \gamma_{20}(INTDIS_{ti}) + \gamma_{30}(SLOPEDIS_{ti}) + \gamma_{40}(Season_{ti}) + u_{0i} + u_{1i}(TIME_{ti}) + u_{2i}(INTDIS_{ti}) + u_{3i}(SLOPEDIS_{ti}) + \log(P_i) \quad (2)$$

$$\log(Y_{ti}) = \gamma_{00} + \gamma_{10}(TIME_{ti}) + \gamma_{20}(INTDIS_{ti}) + \gamma_{30}(SLOPEDIS_{ti}) + \gamma_{40}(Season_{ti}) + u_{0i} + u_{1i}(TIME_{ti}) + \mathrm{u}_{2i}(INTDIS_{ti}) + u_{3i}(SLOPEDIS_{ti}) + \epsilon_{ti} + \log(P_i) \quad (3)$$

$$logit(\lambda_{ti}^{*}) = \pi_{00} + \pi_{10}(Season_{ti}) \quad (4)$$

where t is the month in the study, and i is the index of the neighborhood. We noted that where individuals had different exposures (i.e., the youth population size varies across the 138 neighborhoods), an offset ($\log(P_i)$, where P_i represents the youth population size for neighborhood i) was added to the count model to account for the expected variation that population size would produce in the observed counts. The fixed effect included γ_{00} indicating the initial intercept in March 2019, γ_{10} representing the estimation of the average linear change per month over the 12 months prior to the onset of the pandemic (March 2020) in the rate of delinquency over time, γ_{20} representing the extent to which the onset of the pandemic produced an immediate change in youth offending rate relative to what would have been expected from the pre-transition trend, γ_{30} specifying the average shift in the monthly change in the rate following the pandemic relative to the pre-change slope (γ_{10}), and γ_{40} capturing the seasonal effect. Equations 1–3 also include different numbers of random variances (u_{0i}, u_{1i}, u_{2i}, u_{3i}, and ϵ_{ti}) that are used to meet different assumptions for a count response distribution. The inflation model (Equation 4) is essentially a binary logistic model in which λ_{ti}^{*} models the probability of observing a structural value of zero versus the probability of observing at least one offending count, and the probability is estimated as a logit intercept (π_{00}) controlling for seasonal effect π_{10}.

Poisson, RIP, NB, ZIP, ZI-RIP, and ZI-NB were fitted to each type of offense data (offenses against a person, property offenses, and drug-related offenses) separately. For each outcome variable, the model with the smallest Bayesian information criterion (BIC) evidenced the best-fitting model and would be retained for interpretation (Peugh et al., 2021). Building upon the unconditional DGM, we investigated the extent to which ICE accounted for variances of u_{0i}, u_{1i}, u_{2i}, u_{3i}, and when possible, λ_{ti}^{*}. All ML-GLMM were conducted using "glmmTMB" (Brooks et al., 2017) package embedded in the R environment (R Core Team, 2021).

Results

Selecting the best-fitting longitudinal count model

Table 3 presents BIC for the six ML-GLMM. When the proposed models with freely estimated random effects on $TIME_{ti}$, $INTDIS_{ti}$, and $SLOPEDIS_{ti}$ (the top panel of Table 3), only Poisson and ZIP successfully converged for offenses against a person and property offenses, and all models failed to converge for drug-related offenses. Despite the convergence problems, estimates for the unconditional models with the random-effect variances on $TIME_{ti}$, $INTDIS_{ti}$, and $SLOPEDIS_{ti}$ were provided in Supplementary Tables S1–S3.

The convergence problem made the estimated parameters unreliable. A common reason behind the convergence problem is model overfitting (Hoffman, 2015), such that redundant random effects are specified. A closer inspection of the results suggests that model convergence problems may be due to the small random-effect variance for $TIME_{ti}$ (ranging from 0.000 to 0.009 for offenses against a person, from 0.000 to 0.011 for property offenses, and from 0.000 to

TABLE 3 BIC for unconditional discontinuous growth models.

	Poisson	RIP	NB	ZIP	RI-ZIP	ZINB
Random-effect variances for TIME, INTDIS, and SLOPEDIS were freely estimated						
Offenses against a person	7,557	CP	CP	7,524	CP	CP
Property offenses	6,297	CP	CP	6,237	CP	CP
Drug-related offenses	CP	CP	CP	CP	CP	CP
Random variances for TIME and SLOPEDIS were constrained to 0, whereas random variance for INTDIS were freely estimated						
Offenses against a person	7,946	7,316	CP	7,777	7,318	7,286
Property offenses	6,564	6,156	CP	6,486	6,119	CP
Drug-related offenses	CP	2,627	CP	2,624	2,608	CP

RIP, random intercept Poisson; NB, negative binomial; ZIP, zero-inflated Poisson; RI-ZIP, random intercept zero-inflated Poisson; ZINB, zero-inflated negative binomial; BIC, Bayesian information criterion; TIME, slope prior to the discontinuity; INTDIS, intercept discontinuity; SLOPEDIS, slope discontinuity; CP, convergence problem.

0.005 for drug-related offenses) and $SLOPEDIS_{ti}$ (ranging from 0.001 to 0.014 for offenses against a person, from 0.000 to 0.016 for property offenses, and from 0.000 to 0.003 for drug-related offenses) across the six models. These trivial variances in the slopes indicate that the developmental trajectories for the three types of delinquency operate in a relatively homogenous way across the neighborhoods.

To that end, we reran the six models separately for each type of delinquency by constraining u_{1i} and u_{3i} to be 0. The bottom panel of Table 3 presents BIC for each estimated DGM model. For offenses against a person, ZINB was the best fitting model (BIC = 7,286). Regarding property offenses, RI-ZIP was the best fitting model (BIC = 6,119). For drug-related offenses, RI-ZIP was the best fitting model (BIC = 2,608). Taken together, results from ZINB for offenses against a person and RI-ZIP for property offenses and drug-related offenses adequately reflected the interrupted effect of the COVID-19 pandemic on youth offending rate trend over the 2 years. Full estimates for the unconditional models with random-effect variance on $INTDIS_{ti}$ are presented in Supplementary Tables S4–S6.

The interrupted developmental trajectories of delinquency among youth

Table 4 provides the fixed effects, random effects, and model fit for the best-fitting models for the three types of offenses. The expected count of offenses against a person for a typical neighborhood (the number of population for youth between 10 and 19 years of age is 4,906) in a typical season ($Season_{ti}$ = 0) in March 2019 was 0.933 [$4{,}906 * \frac{1}{1+\exp^{(\pi_{00})}} * \exp^{(\gamma_{00})} = 4{,}906 * \frac{1}{1+\exp^{(-6.823)}} * \exp^{(-8.566)}$]. The relative change in the rate of offenses against a person decreased over time during the 1 year period prior to the pandemic by 1.6% [$\left(1-\exp^{\gamma_{10}}\right) \times 100\% = \left(1-\exp^{-0.016}\right) \times 100\%$]. While holding the seasonal effect constant, the instantaneous decrease in the count of offenses against a person at the onset of the pandemic (i.e., March 2020) when social regulations first came into effect for a typical neighborhood was 0.553 [$4{,}906 * \frac{1}{1+\exp^{\pi_{00}}} * \exp^{(\gamma_{00}+\gamma_{20})} = 4{,}906 * \frac{1}{1+\exp^{(-6.823)}} * \exp^{(-8.566-0.524)}$]. A proportional incidence rate ratio (IRR) comparison showed an 28.3% $\left[\frac{\exp^{(\gamma_{00}+\gamma_{10}*12)} - \exp^{(\gamma_{00}+\gamma_{20})}}{\exp^{(\gamma_{00}+\gamma_{10}*12)}} * 100\% = \frac{\exp^{(-8.566-0.016*12)} - \exp^{(-8.566-0.524)}}{\exp^{(-8.566-0.016*12)}} * 100\%\right]$ instantaneous decrease in generated IRR of offenses against a person in March 2020 compared to the expected IRR. The expected change in the rate of offenses against a person following the implementation of containment measures did not significantly differ from the change in the rate prior to the COVID-19 pandemic ($\gamma_{30} = -0.004$, $p = 0.773$), suggesting an absence of long-term change following the pandemic relative to prior to the pandemic.

Figure 2 shows the model predicted count for offenses against a person prior to, at, and following the implementation of containment measures for a typical neighborhood after taking seasonal effect into account. The model predicted count for offenses against a person was 0.870, 0.862, 0.456, 0.444, and 0.414 in January, February, March, April, and May of 2020, indicating that the onset of the COVID-19 pandemic dramatically reduced the count of offenses against a person. The figure also emphasized the seasonal effect on offenses against a person such that individuals were more likely to commit offenses against a person during spring and winter when the temperature is moderate and pleasant rather than summer and fall in Houston when the temperature is high and unpleasant.

TABLE 4 Unconditional discontinuous growth models for the three types of delinquency.

	Offenses against a person[a]	Property offenses[b]	Drug-related offenses[b]
Count model			
Fixed effects			
Intercept (γ_{00})	−8.566*** (0.085)	−8.819*** (0.094)	−8.686*** (0.093)
TIME(γ_{10})	−0.016* (0.008)	−0.009 (0.009)	−0.240*** (0.015)
INTDIS (γ_{20})	−0.524*** (0.106)	−0.355** (0.122)	0.404 (0.247)
SLOPEDIS (γ_{30})	−0.004 (0.013)	−0.053*** (0.015)	0.182*** (0.033)
Season (γ_{40})	−0.008** (0.003)	−0.001 (0.004)	−0.002 (0.008)
Random effects (variance)			
Intercept (VAR[u_{0i}])	0.563	0.556	0.343
INTDIS (VAR[u_{2i}])	0.007	0.094	0.000
Dispersion	6.71	N/A	N/A
Zero-inflated model			
Intercept (π_{00})	−6.823** (2.364)	−1.565*** (0.175)	−3.775*** (1.035)
Season (π_{10})	0.374* (0.176)	0.021 (0.018)	0.345*** (0.083)
Model fit			
DF	11	10	10
LogL	−3,599	−3,019	−1,263
BIC	7,286	6,119	2,608

TIME, slope prior to the discontinuity; INTDIS, intercept discontinuity; SLOPEDIS, slope discontinuity; VAR, variance; DF, degrees of freedom; LogL, log likelihood; BIC, Bayesian information criterion.
[a]Zero-inflated negative binomial model.
[b]Random intercept zero-inflated Poisson model.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

The expected count for property offenses for a typical neighborhood in a typical season in March 2019, was 0.600 [$4{,}906 * \frac{1}{1+\exp^{(-1.565)}} * \exp^{(-8.819)}$]. The pre-pandemic change in the rate of property offenses was effectively 0 ($b = -0.009$, $p = 0.349$), indicating that the rate of property offenses did not change across the 12 months prior to the onset of the pandemic. The expected count of property offenses at the onset of the pandemic (i.e., March 2020) dropped to 0.421 [$4{,}906 * \frac{1}{1+\exp^{(-1.565)}} * \exp^{(-8.819-0.355)}$], suggesting an immediate reduction. A proportional IRR comparison showed a 21.9% [$\frac{\exp^{(-8.819-0.009*12)} - \exp^{(-8.819-0.355)}}{\exp^{(-8.819-0.009*12)}} * 100\%$] instantaneous decrease in the generated rate of property offenses than the expected rate. Following the onset of the pandemic, the expected property offenses rate decreased by 6.0% [$\left(1-\exp^{(-0.009-0.053)}\right)\times 100\%$] per month, on average. Compared to the fluctuation of property offenses 1 year prior to the pandemic, the systematic and long-term decrease of property offenses 1 year following the pandemic indicates the enduring impact of the pandemic on property offenses.

Figure 3 shows the model predicted count of property offenses prior to, at, and following the COVID-19 pandemic for a typical neighborhood after taking seasonal effect into account. A statistically significant downfall in property offenses occurred between February and March 2020. In addition, the count of property offenses fluctuated prior to the onset of the pandemic, whereas there was a decreasing trend over time following the pandemic. Interestingly, there was no pattern in terms of the change echoing the insignificant seasonal effect for property offenses.

Regarding drug-related offenses, the expected count of drug-related offenses for a typical neighborhood in a typical season in March 2019 was 0.810 [$4{,}906 * \frac{1}{1+\exp^{(-3.775)}} * \exp^{(-8.686)}$]. The expected rate of drug-related offenses decreased over the 12-month

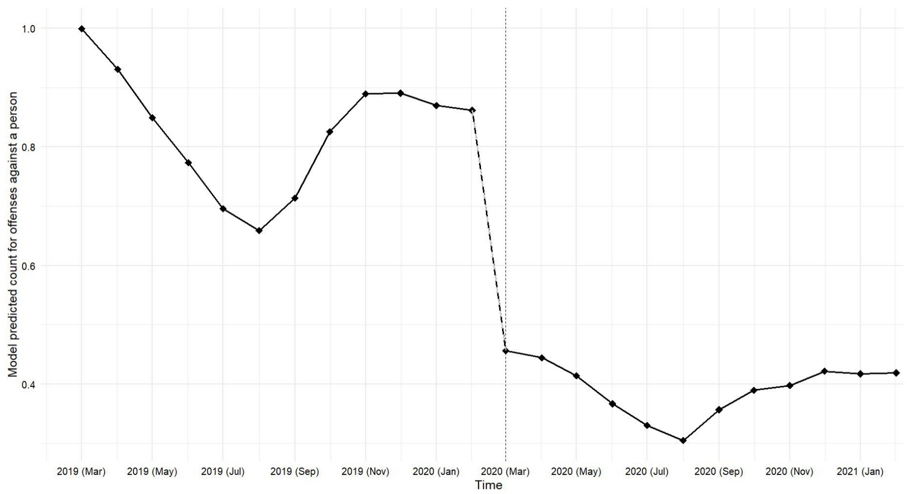

FIGURE 2
Model predicted counts for offenses against a person prior to, at, and following the COVID-19 pandemic by taking seasonality into account. The X-axis represents months prior to (March 2019 to February 2020), at (March 2020, the vertical dashed line), and following (April 2020 to February 2021) the school closures. Y-axis represents the model predicted mean count. The dashed vertical line indicates the month when containment measures started to be implemented. The dashed oblique line highlights the abrupt jump in offense count between 1month before the implementation of the containment measures and the month after implementing these containment measures.

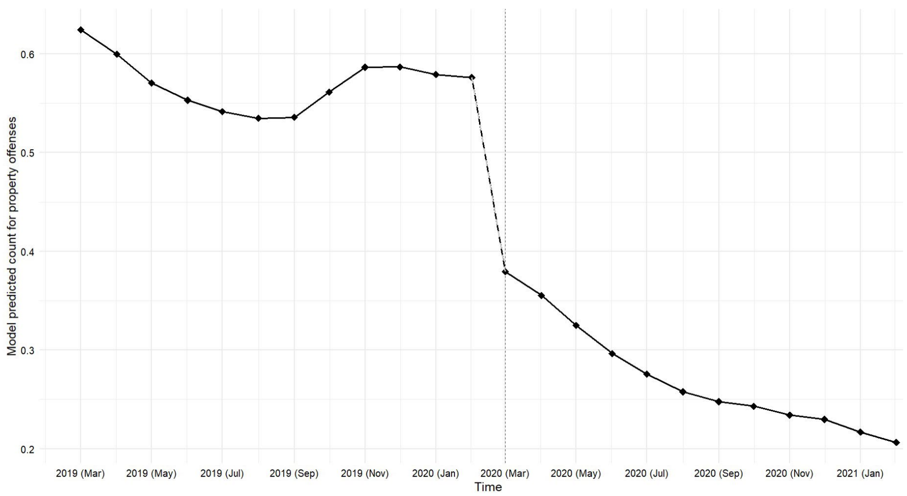

FIGURE 3
Model predicted count for property offenses prior to, at, and following the COVID-19 pandemic by taking seasonality into account. The X-axis represents months prior to (April 2019 to February 2020), at (March 2020, the vertical dashed line), and following (April 2020 to February 2021) the school closures. Y-axis represents the model predicted mean count. The dashed vertical line indicates the month when containment measures started to be implemented. The dashed oblique line highlights the abrupt jump in offense count between 1month before the implementation of the containment measures and the month after implementing these containment measures.

period prior to the onset of the pandemic by 21.3% [$\left(1-\exp^{-0.240}\right)\times 100\%$] per month, on average. When the pandemic hit, the generated rate of drug-related offenses was not significantly different from the expected rate ($\gamma_{30}=0.404$, $p=0.102$), suggesting a lack of immediate change. Following the COVID-19 pandemic, the expected property offenses rate decreased by 5.6% [$\left(1-\exp^{(-0.240+0.182)}\right)\times 100\%$] per month, on average, suggesting that the decreasing trend following the pandemic became much less steep compared to the declining trend prior to the pandemic.

Figure 4 clearly shows the noticeable decline in the average count of drug-related offenses 1 year prior to the onset of the pandemic, whereas the decreasing change became significantly less steep following the pandemic as compared to prior to the pandemic. Importantly, there was no significant shift to the count in March 2020 when the pandemic hit. It should be noted that although the season had no effect on the count of drug-related offenses, it was associated with the likelihood of having no drug-related offenses versus more than one drug-related offense in any month ($\pi_{10}=0.345$, $p<0.001$).

The effect of concentrated affluence and poverty on the variation of the discontinuity of delinquency

After establishing the interrupted developmental trajectories for the three types of delinquency (ZINB for offenses against a person and RI-ZIP for property offenses and drug-related offenses), we proceeded to evaluating the extent to which ICE accounted for the random-effect variance on $INTDIS_{ti}$ (i.e., u_{2i}). Note that the associations of ICE with u_{1i} and u_{3i} were not evaluated, because they were constrained to be 0 as illustrated above.

The conditional count model for offenses against a person was as follows:

$$\begin{aligned}\log\left(Y_{ti}\right)&=\gamma_{00}+\gamma_{10}\left(TIME_{ti}\right)+\gamma_{20}\left(INTDIS_{ti}\right)\\&+\gamma_{30}\left(SLOPEDIS_{ti}\right)+\gamma_{40}\left(Season_{ti}\right)\\&+\gamma_{01}\left(ICE_{i}\right)+\gamma_{21}\left(ICE_{i}\times INTDIS_{ti}\right)+u_{0i}\\&+u_{2i}\left(INTDIS_{ti}\right)+\epsilon_{ti}+\log\left(P_{i}\right)\end{aligned}\quad(5)$$

The conditional count model for property offenses and drug-related offenses was

$$\begin{aligned}\log\left(Y_{ti}\right)&=\gamma_{00}+\gamma_{10}\left(TIME_{ti}\right)+\gamma_{20}\left(INTDIS_{ti}\right)\\&+\gamma_{30}\left(SLOPEDIS_{ti}\right)+\gamma_{40}\left(Season_{ti}\right)\\&+\gamma_{01}\left(ICE_{i}\right)+\gamma_{21}\left(ICE_{i}\times INTDIS_{ti}\right)+u_{0i}\\&+u_{2i}\left(INTDIS_{ti}\right)+\log\left(P_{i}\right)\end{aligned}\quad(6)$$

The inflation model was

$$logit\left(\lambda_{ti}^{*}\right)=\pi_{00}+\pi_{10}\left(Season_{ti}\right)+\pi_{01}\left(ICE_{i}\right)\quad(7)$$

Table 5 presents results pertaining to the effect of ICE on the variation of the initial intercept and the discontinuity of the intercept. Yet, the three conditional models had convergence problems, suggesting that estimates may not be reliable. Sensitivity analyses reveal that the convergence problems trivially distort the key estimates— γ_{01} and γ_{21}. Despite the heterogeneity in terms of BIC among the six unconditional models for each type of delinquency (Supplementary Tables S4–S6), we developed corresponding conditional models for sensitivity analyses. Supplementary Tables S7–S9 present the results. It appears that the direction of the estimates of interest— γ_{01} and γ_{21} —was all the same

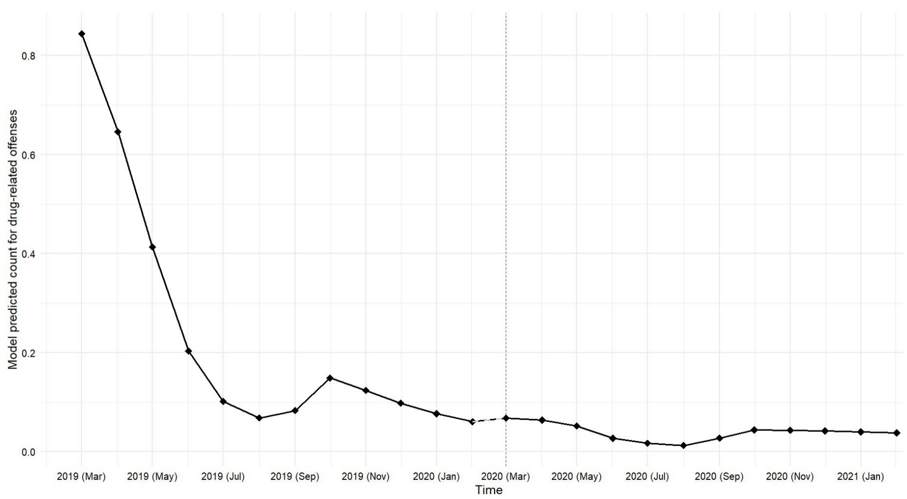

FIGURE 4
Model predicted count for drug-related offenses prior to, at, and following the COVID-19 pandemic by taking seasonality into account. The X-axis represents months prior to (April 2019 to February 2020), at (March 2020, the vertical dashed line), and following (April 2020 to February 2021) the school closures. Y-axis represents the model predicted mean count. The dashed vertical line indicates the month when containment measures started to be implemented. The dashed oblique line highlights the abrupt jump in offense count between 1month before the implementation of the containment measures and the month after implementing these containment measures.

TABLE 5 Conditional discontinuous growth models for accounting for variations in the discontinuity by concentrated affluence and poverty.

	Offenses against a person[a]	Property offenses[b]	Drug-related offenses[b]
Count model			
Fixed effects			
Intercept	−8.459*** (0.071)	−8.699*** (0.080)	−8.628*** (0.086)
TIME	−0.016 (0.008)	−0.009 (0.009)	−0.240*** (0.015)
INTDIS	−0.533*** (0.104)	−0.326** (0.114)	0.400 (0.247)
SLOPEDIS	−0.003 (0.013)	−0.053*** (0.015)	0.181*** (0.033)
Season	−0.006* (0.003)	−0.001 (0.004)	−0.003 (0.008)
ICE	−2.301*** (0.264)	−2.384*** (0.318)	−1.978*** (0.334)
ICE* INTDIS	−0.195 (0.239)	0.221 (0.283)	−0.202 (0.617)
Random effects			
Intercept	0.276	0.241	0.203
INTDIS	0.000	0.000	0.000
Dispersion	6.86	N/A	N/A
Zero-inflated model			
Intercept	−6.679*** (1.853)	−1.453*** (0.170)	−3.976*** (1.092)
Season	0.372** (0.140)	0.018 (0.017)	0.360*** (0.087)
ICE	4.081*** (1.181)	0.958 (0.907)	−0.391 (1.099)
Model fit			
DF	14	13	13
LogL	CP	CP	CP
BIC	CP	CP	CP

ICE, Index of Concentration at the Extremes; TIME, slope prior to the discontinuity; INTDIS, intercept discontinuity; SLOPEDIS, slope discontinuity; DF, degrees of freedom; LogL, log likelihood; BIC, Bayesian information criterion; CP, convergence problem.
[a]Zero-inflated negative binomial model.
[b]Random intercept zero-inflated Poisson model.
*$p<0.05$, **$p<0.01$, ***$p<0.001$.

and differences of estimates occur at the first decimal place. If making a dichotomous reject-nonrejected decision, the six conditional models for each type of delinquency would lead to the same conclusion: a higher ICE was related to a lower initial intercept, and ICE was not related to discontinuity. Thus, to be consistent with the unconditional models presented in Table 4, we presented estimates derived from the corresponding conditional models in Table 5, though with convergence problems.

For the three types of offenses, a higher ICE was related to a lower initial intercept ($\gamma_{01}=-2.301$, $p<0.001$ for offenses against a person; $\gamma_{01}=-2.384$, $p<0.001$ for property offenses; $\gamma_{01}=-1.978$, $p<0.001$ for drug-related offenses). In March 2019 (1 year prior to the pandemic), the expected count of offenses against a person for a typical neighborhood, for example, was 0.110 $\left[4{,}906 * \frac{1}{1+\exp^{(-6.679-0.372*8.99+4.081)}} * \exp^{(-8.459+0.006*8.99-2.301)}\right]$, 1.098 $\left[4{,}906 * \frac{1}{1+\exp^{(-6.679-0.372*8.99)}} * \exp^{(-8.459+0.006*8.99)}\right]$, and 10.959 $\left[4{,}906 * \frac{1}{1+\exp^{(-6.679-0.372*8.99-4.081)}} * \exp^{(-8.459+0.006*8.99+2.301)}\right]$ for neighborhoods with absolute concentrated affluence (ICE = 1), with equally affluent and disadvantaged families (ICE = 0), and absolute concentrated disadvantaged families (ICE = −1), respectively. Neighborhoods with absolute concentrated disadvantage had a rate of offense against a person 8.982 ($\frac{1.098-0.110}{0.110}$) and 98.627 ($\frac{10.959-0.110}{0.110}$) times greater than neighborhoods with equally affluent and disadvantaged families and absolute concentrated affluence, respectively, 1 year prior to the onset of the COVID-19 pandemic. However, ICE was not significantly associated with the shift of the intercept for offenses against a person ($\gamma_{21}=-0.195$, $p=0.415$), property offenses ($\gamma_{21}=0.221$, $p=0.434$), and drug-related offenses ($\gamma_{21}=-0.202$, $p=0.744$).

Discussion

The present study advances the literature by providing insight into (a) the immediate and long-term change of youth delinquency in offenses against a person, property offenses, and drug-related offenses in the context of COVID-19 and (b) the effects of concentrated affluence and poverty on the interrupted developmental trajectories of delinquency. By applying the rigorous DGM under the ML-GLMM framework, we found that (1) the onset of the COVID-19 pandemic was associated with an immediate reduction in offenses against a person and property offenses but not in drug-related offenses; (2) the post-transition trends for property offenses and drug-related offenses were significantly different from their corresponding pre-transition trends; (3) the pre-transition trends and the relative post-transition trends for the three types of delinquency were relatively homogenous across the neighborhoods; and (4) ICE did not account for variations of the immediate change for the three offending types.

The abrupt impact of the COVID-19 pandemic on youth delinquency

In line with prior research based on a sample of youth in Australia (McCarthy et al., 2021), we found an immediate decrease in offenses against a person and property offenses, but not drug-related offenses. Revital and Haviv (2022), however, reported a significant reduction in assaults during lockdowns and in drug-related offenses during the pandemic, whereas property offenses remained unchanged. The inconsistent findings are difficult to reconcile due to substantial variations in operationalizing crime types, jurisdictions, and follow-up periods. Nevertheless, in combination with existing research for youth (McCarthy et al., 2021; Revital and Haviv, 2022) and adults (e.g., Felson et al., 2020; Mohler et al., 2020; Nivette et al., 2021), the present study demonstrates that the altered routine activities caused by the COVID-19 pandemic exerted an abrupt impact on crime and delinquent behavior.

Stay-at-home restrictions, social distancing, school closures, remote instruction, and barring gatherings, among others, largely reshaped the patterns of social connection and movement for youth. Parents had to structure the ordinary activities of everyday life for their children across all school years. For example, parents had to ensure their children attended virtual classes on time. Parents also had to consider and support their children's activities in their spare time. According to the U.S. Census Bureau's 2020 Survey of Income and Program Participation, for example, 69% of parents reported reading to young children five or more times per week, compared with 65% in 2018 and 64% in 2019 (Mayol-Garcia, 2022). Importantly, the presence of parents at home *per se* has been claimed to be a primary factor in shrinking delinquency opportunities for youth due to increased social control and censorship (Osgood et al., 1996; Hawdon, 1999).

Moreover, the conventional face-to-face interactions between youth that commonly happen in school buildings and other elements of the built environment were largely replaced with virtual communications following the implementation of containment measures. Juvenile delinquency is primarily a group phenomenon, as being accompanied by adolescent peers makes deviance easier and more rewarding (Sampson and Groves, 1989; Osgood et al., 1996). In the context of COVID-19, however, the reduced in-person social interactions between youth decreased the situational potential for deviance by making delinquency more challenging and devaluing the symbolic and tangible rewards of committing shared delinquent behavior (Osgood et al., 1996). Moreover, the prohibition of private and public gatherings and closures of non-essential businesses and entertainment significantly reduced the number of potential victims.

Thus, the immediate reduction in offenses against a person and property offenses can be partially attributable to (a) the presence of guardianship, (b) the inhibited motivation to conduct delinquency due to the drastic reduction of face-to-face interactions with peers, and (c) the lack of access to victims (i.e., less opportunity for victimization) caused by remote instructions. It should be noted that the impact of various social restrictions on the immediate change of the youth offending count is likely to involve more complicated mechanisms than the ones we proposed here. For instance, it is unclear whether the absence of peers, the reduced exposure to potential victims, the presence of authoritative figures, and structured activities contribute to the change in a linear or nonlinear manner.

The enduring impact of the COVID-19 pandemic on youth delinquency

While existing research exploiting time series analysis and its extensions have emphasized the abrupt change of offenses during the pandemic, the DGM approach used in the current study offered insight into the enduring impact of the COVID-19 pandemic on youth delinquency. This was achieved by comparing the post-transition slope (the change following the pandemic) with the pre-transition slope (the change prior to the pandemic). As a baseline, youth delinquency rates were assumed to fluctuate over time without demonstrating any systematic change after controlling for the seasonal variants prior to the acute event occurring (i.e., March 2020). This assumption was supported for property offenses. Despite the declining pre-transition slope for offenses against a person, its changing rate was trivial (1.6%). Regarding drug-related offenses, Harris County initiated a policy that the District Attorney's office did not prosecute some possession of marijuana cases (personal use—less than 2 oz) in July 2019, and since then, those cases have no longer been tracked by HCJPD. The systematic declining trend for drug-related offenses prior to the pandemic (pre-transition slope) confounded this drug-related policy, so it failed to establish a plausible baseline to be compared with the post-transition slope. Thus, interpreting the relative change of the post-transition slope compared to the pre-transition slope for drug-related offenses is not as robust as for offenses against a person and property offenses.

We observed a steeper decline in property offenses following the pandemic as compared to the trend 1 year prior to the pandemic, implying, perhaps, an enduring impact of the COVID-19 pandemic on youth delinquency. In the context of COVID-19, parents or caregivers faced unprecedented financial stressors resulting from unemployment and recession, which drained their mental and emotional resources. In order to negotiate such an unprecedented challenge, the disruption caused by the pandemic might trigger the resilience mechanisms in family dynamics, including clear information, enhanced emotional sharing, collaborative problem-solving, and heightened hope (Prime et al., 2020). It is presumable that such family resilience in response to the pandemic was formulated in an accumulating and gradual manner rather than an acute manner. The intact family dynamics have the potential to enhance child attachment to their parents, which is hypothesized to impede delinquent behavior (Hirschi, 1969). The enduring impact of the pandemic on the long-term decline of property offenses highlighted the process-oriented nature of the pandemic. According to EST (Morgeson et al., 2015), COVID-19 presumably triggered multilayer paths of subsequent events, whereby some would result in a positive change of behavior (e.g., family resilience), whereas others would result in a negative change of behavior (e.g., coercive and harsh parenting), depending on the features of these subsequent events. The steeper declining trend for property offenses may reveal that the positive consequences outweigh the negative consequences stimulated by the event in determining this type of delinquency.

Regarding offenses against a person, the pre-transition and post-transition slopes paralleled, suggesting that the pandemic did not exert an extra and enduring impact on offenses against a person. Following the reasoning elaborated above, the lack of long-term change in offenses against a person may be interpreted as the result of a combined effect of strengthened bonds (e.g., family resilience), on the one hand, and worsened bonds (e.g., unhealthy parent–child relationship caused by problematic forms of parenting while parents faced the unprecedented strain) on the other, within the family. A competing interpretation is that the COVID-19 pandemic may not stimulate chains of subsequent events that are strong enough to influence violent behavior. Indeed, violent behavior, including offenses against a person, typically has a strong continuity between childhood, adolescence, and adult life (Rappaport and Thomas, 2004). To that end, criminal propensities such as early initiation of delinquency, low self-control, parental criminality, mental disorders, and child maltreatment (Hawkins et al., 1998) are presumably more relevant to youth violence than the cumulative yet gradual change of individual and collective behavior triggered by the pandemic. Considering the heterogeneity regarding the enduring impact of the COVID-19 pandemic on offenses against a person and property offenses suggests that the mechanisms through which the pandemic affected youth offending depended on the type of delinquency.

The concentration of affluence and poverty and youth delinquency during the COVID-19 pandemic

We found that the concentration of affluence and poverty, as indexed by ICE, was associated with lower initial delinquency rates (counts in March 2019, 1 year prior to the pandemic) for offenses against a person, property offenses, and drug-related offenses. This finding is partially consistent with McCarthy et al. (2021), whereby they found that community SES (a composite of employment, education, welfare payments, and housing) was associated with lower initial intercept for offenses against a person and property offenses but not illicit drug offenses. These findings together imply that low SES communities are characterized by a relatively poor ability to supervise and control teenage peer groups, which in turn may increase the opportunities for committing crime and delinquency (Sampson and Groves, 1989).

Consistent with McCarthy et al. (2021), we observed that ICE was not associated with the immediate reduction in offenses against a person and drug-related offenses. Although McCarthy et al. (2021) reported that the pandemic mitigated the rate of property offending such that the disparity of property offenses between low and high SES communities narrowed down following the pandemic, our findings showed that the pandemic was not associated with the immediate reduction in property offenses. One explanation of the discrepant findings centers around the power and sample size. Moderation for ML-GLMM is notoriously underpowered to detect significant effects (Peugh et al., 2021). There were 138 neighborhoods included in the current study as compared to more than 500 communities involved in McCarthy et al. (2021). Another explanation of the discrepancy pertains to the conceptualization of reduction. For McCarthy et al. (2021), the reduction in property offenses referred to the difference between the average offending count from April and June 2020 and the average offending count from January 2018 to March 2020. However, we focused on the immediate reduction in March 2020. Thus, the different ways of quantifying the reduction make comparable interpretations challenging.

Beyond the methodological and conceptual considerations, the findings that ICE did not account for variations in the immediate reduction in the three types of delinquency may be a consequence of the nature of ICE. According to the social disorganization theory (Sampson and Groves, 1989), neighborhood contexts, including poverty, racial/ethnic heterogeneity, and residential mobility, influence crime and delinquency indirectly through informal and formal social control. In other words, ICE is hypothesized to play a role in delinquency through social control. To that end, the influence of ICE on youth delinquency is arguably weaker than the influence of social control. It is possible that neighborhood social control contributes to the variation instead of the manifest concentration of affluence and poverty. Thus, it is worthwhile for the future to consider social control while investigating the extent to which community characteristics influence the abrupt reduction of delinquency during the pandemic.

Limitations and future directions

There are several limitations of the current study that need to be noted. First, the results reported here are specific to the jurisdiction in Harris County, so it may not generalize to other jurisdictions in the U.S. In fact, a consistent finding derived from existing research is that the impact of the pandemic on crime and delinquency varies as a function of jurisdictions and regions (e.g., Ashby, 2020). Second, given the related lack of precision and suppressed reflection of variability within and between the county's neighborhoods, using zip codes as indicators of SES is another limitation.

Third, it is important to note that delinquency rates are susceptible to police activity and enforcement. Nielson et al. (2022) examined the impact of COVID-19 on police reactive and proactive activities in Houston, Texas. For police reactive activities, police response to violent crime calls significantly increased after COVID-19. Police response to traffic-related calls, property crime, and service-related calls all decreased significantly in the weeks after the announcement of the COVID-19 pandemic. Officers were engaged in more frequent self-initiated patrol activities compared to the pre-pandemic data. Thus, future research needs to take police activity into consideration while evaluating the association between the pandemic and offending in order to obtain robust estimates.

Fourth, given its easy accessibility for scholars, official records have been the dominant data sources when studying the interrupted effect of the pandemic on crime and delinquency; however, such records have been stated to reflect the tip of the iceberg for delinquent behavior because most of such behaviors are unregistered by law enforcement (Moffitt, 1993). Future research utilizing self-report data can complement existing evidence about the pandemic and offending based on recorded crime and delinquency.

Conclusion

We conclude that the COVID-19 pandemic not only had an abrupt but also an enduring impact on juvenile delinquency. The sudden alternation of routine activities was related to the immediate reduction of delinquency in offenses against a person and property offenses at the onset of the pandemic. Meanwhile, subsequent events triggered by the pandemic were associated with the systematic declining trend in property offenses. Although the concentration of affluence and poverty did not mitigate the disparity regarding the immediate reduction of offenses against a person and property offenses across neighborhoods, there was no evidence showing that it exacerbated the disparity. Beyond that, we call for future research to redirect the focus from whether the COVID-19 pandemic had influenced criminal and delinquent behavior to how the impact had occurred. Without gaining an insight into the mechanisms behind the change in offending during the pandemic, all interpretations and implications accumulated from the large body of existing research, as well as the current study, are deducted based on criminological theories. Such a deduction, without further data-based verification, undermines the validity of the implications. Thus, it is imperative for future research to collect retrospective data characterizing the social, emotional, and psychological characteristics of youth, parents, peers, and teachers and investigate how the changes in conventional activities contributed to the change in criminal and delinquent behavior. A better understanding of the mechanisms behind the abrupt and enduring effects of the pandemic on offending would solidify existing studies and improve the precision of designing programs to inhibit criminal and delinquent involvement.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the University of Houston Committee for the Protection of Human Subjects Harris County Juvenile Probation Department. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

NL and EG contributed to the conception and design of the study and drafted the manuscript. DQ and MS provided the data. NL analyzed the data. All authors have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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EDITED BY
Brett Miller,
National Institutes of Health (NIH),
United States

REVIEWED BY
Rui Alexandre Alves,
University of Porto, Portugal
Erik A. Ruzek,
NWEA, United States

*CORRESPONDENCE
Velma McBride Murry
✉ velma.murry@vumc.org

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Implications of built and social environments on the academic success among African American youth: testing Strong African American Families intervention effects on parental academic racial socialization

Velma McBride Murry[1]*, Catherine M. Gonzalez[2], Marlena L. Debreaux[2], Erica E. Coates[3] and Cady Berkel[4]

[1]Department of Human and Organizational Development, Department of Health Policy, School of Medicine, Peabody College, Vanderbilt University, Nashville, TN, United States, [2]Department of Human and Organizational Development, Vanderbilt University, Nashville, TN, United States, [3]Department of Psychiatry, MedStar Georgetown University Hospital/Georgetown University School of Medicine, Washington, DC, United States, [4]College of Health Solutions, Arizona State University, Tempe, AZ, United States

Studies exploring widening academic disparities have highlighted the role of racialized school settings, which have given way to incidents of discrimination and unfair treatment for students of color, disproportionately affecting African American youth. Research also shows that family-based preventive interventions may avert negative outcomes for this population through the promotion of protective socialization practices. Consequently, the current study tests the efficacy of a culturally tailored preventive family-based program to foster induced changes in academic promotive parenting practices that prepare youth to advance academically by navigating negative race-related experiences in school settings. Data collected over four time periods from the Strong African American Families (SAAF) efficacy trial (Murry and Brody, 2004) with 667 African American families in rural Georgia were used for this study. Structural equation modeling analyses demonstrated that the SAAF program was associated with positive intervention induced changes in parental academic race-related socialization, which in turn, was indirectly associated with reduced school compromising behaviors through the enhancement of racial pride. While discrimination compromised academic success, our findings highlight the protective nature of racial pride in dissuading academic failure and school dropout through the promotion of academic success. This study confirms that a family-based prevention program holds promise to address academic disparities through the enhancement of parenting and youth protective processes that buffer youth from succumbing to racialized social environments such as schools. Implications for research, educational policy, and preventive interventions are discussed.

KEYWORDS

family-based prevention, academic racial socialization, academic success, school climate, academic disparities

Introduction

The foundational role of schools in the community has been established through multiple systems that are structurally and functionally integrated and embedded in history and sociocultural systems, including educational, public policy, governmental and economic systems. Studies examining the effects of school climate and social environment have focused on ways in which social interactions and the quality of one's surroundings or physical environment impacts human development and behavior (Stewart et al., 2021). Thus, studies of schools as social environments have explored ways in which teacher and peer relationship quality, school policies, as well as parental school involvement predict youths' academic aspirations and school performance (Marchand et al., 2014; Kwong and Davis, 2015; Berkowitz et al., 2017). Negative school experiences have been identified as drivers of academic disparities, with notable detriment for African American youth, who are among the most vulnerable of populations experiencing educational marginalization in the United States (Morris and Perry, 2017; Causadias and Umaña-Taylor, 2018; Gaylord-Harden et al., 2018; Welsh and Little, 2018; Jones et al., 2021). It has also been established that family-based preventive interventions may avert negative outcomes for this population through the promotion of protective practices such as academic and racial socialization (Murry et al., 2019; Berkel et al., 2022). The goal of the current study was to determine whether a strengths-based and culturally centered, family-based preventive intervention would be effective in enhancing parenting processes that encourage their children to thrive academically, by buffering them from succumbing to the negative consequences of race-related social interactions experienced in school. In the following section we provide a brief overview of studies that informed the conceptualization of our study.

Schools as racialized social environments

While school should be a place of safety for African American youth, it is often a social setting where stressful race related experiences begin as early as pre-kindergarten, followed by continued episodes of being scapegoated by educational systems as uneducable because of disruptive, aggressive, and oppositional behaviors displayed in school settings (Gibbons et al., 2004; Murry et al., 2009; Dumas, 2016). Race related experiences can occur through numerous social interactions, including peers, teachers, authority figures, or the internet. These race related experiences can be manifested as microaggressions, implicit biases, or explicit and vicarious verbal and physical incidents of discrimination fueled by systems and structures of inequalities (English et al., 2020). One of the consequences of growing up in a racialized society is the negative characterization and social marginalization of African American students, which set forth perceptions of low expectations about their aptitude, scholastic capacities, intellectual competence, and overall morality (Chin et al., 2020). Race related experiences and negative stereotyping of African American students in school settings begin as early as pre-K.

Several studies report significant levels of racial discrimination as early as age 3–4 years old (Caughy et al., 2004) which increases in frequency as African American children age (Fisher et al., 2000; Gibbons et al., 2004; Sellers et al., 2006). For example, recent research indicates that, on average, African American adolescents experience over five racial discrimination experiences a day (English et al., 2020), with girls and boys undergoing similar racialized experiences in schools. While much attention has been given to the ill effects of racial discrimination on the plight of African American males' school experiences, several studies have also shown that African American girls are also at risk for disproportionate detentions, suspensions, and expulsions (Young and Butler, 2018). African American boys, for example, were twice as likely to be recipients of harsh disciplinary practices and infractions than White boys; however, African American girls were three times more likely to experience inequitable disciplinary practices compared to White girls (Morris and Perry, 2017). Out-of-school suspension and expulsion practices, in particular, were often driven by teachers' negative stereotypes of African American youth, characterizing boys as "unteachable," aggressive, and violent (James, 2012). Girls, on the other hand, were often described as sassy, loud, and defiant toward teachers and school personnel (Cooper et al., 2022). These stereotyped perceptions of teachers are thought to be major contributors to not only disparities in school disciplinary practices, but ultimately drivers of widening academic disparities for African American youth, through reduced academic engagement (Larson et al., 2019).

Academic failure and school dropout

A plethora of studies have documented association between race related experiences and school outcomes. For example, several studies found that pervasive acts of implicit racial attitudes, as well as implicit bias and explicit acts of racial discrimination from teachers toward African American students have been associated with African American students' academic failure and school dropout (Wang and Huguley, 2012; Chin et al., 2020). Further, being subjected to punitive disciplinary practices, including detentions, suspensions, expulsions, and assignments to alternative schools or special education classes (Skiba et al., 2002) have been associated with academic failure. Confronted with a sense of "otherness" from teachers and school professionals, African American students may cope with racial discrimination by disengaging cognitively and physically from schools to avoid negative race-related encounters (Murry et al., 2009). Moreover, some students may engage in self-protection behaviors, namely *academic self-presentation*, often camouflaging their academic ability, and potentially jeopardizing their academic performance and school success (Ogbu,1992; Murry et al., 2009; Cooper et al., 2022). Other students, who experience teacher racialized victimization, may physically disengage through increased school absences, heightened social isolation and alienation, academic deterioration, and eventually, dropping out of school (Strange et al., 2012; Leath et al., 2019). To cope with these negative social interactions, many African American students engage in coping behaviors that may become a self-fulfilling prophecy, such when students disengage academically, it confirms teachers' negative stereotyped perceptions of their academic potential. Given that many African American youth do not succumb to race related adversities, it is important to identify factors and processes that explain how they are able to successfully navigate these seemingly insurmountable odds to become successful contributing members of society.

Parents and prosocial peers as academic influencers

Several studies have demonstrated the protective nature of African American parents' capacity to socialize their children in a positive way, through which youth learn to be aware of racism and reject negative societal messages about their race (Murry et al., 2009; Wang and Huguley, 2012). In fact, powerful factors that protect African American youth originate in the family, particularly in caregiving practices (Brody et al., 2005). For example, African American parents, recognizing the likelihood that their children will be exposed to disparate treatment in schools due to racism and discrimination, socialize and motivate their children to do well in school (Hill et al., 2004; Murry et al., 2009). Socialization practices to prepare youth for racial bias and marginalization have not only been shown to increase awareness of discrimination and "othering," but also to promote youths' capacity to reject negative societal messages about one's race, and thereby succeed (Chavous et al., 2003; Murry et al., 2009). Cultural socialization, or teaching youth to identify with and take pride in their cultural backgrounds has been consistently associated with improved academic outcomes (Hughes et al., 2006; Neblett et al., 2006; Wang et al., 2020). For example, previous research found that cultural socialization attenuated the effects of teacher discrimination on grade point averages and educational aspirations (Wang and Huguley, 2012). According to Wang and Huguley (2012), preparing youth of color for racial discrimination and teaching them to embrace their racial heritage buffered the negative influence of race-related experiences in schools and in turn, dissuaded school failure. The protective nature of adaptive racial socialization for rural African American youth's school success has also been observed (Murry et al., 2009).

In fact, many African American families have important strengths that foster resilience and, in turn, help their children develop into competent individuals (Murry et al., 2018). Positive parent–child relationships that are emotionally and instrumentally supportive are protective and foster the enhancement of emotional regulation and cognitive control capacities among youth (Morris et al., 2017). These internal self-management processes have been associated with behaviors that foster academic success, including planful decision-making, capacity and skills for paying attention, avoiding distraction, setting priorities, controlling impulses, and recognizing, understanding, and accepting emotions (Hughes and Dexter, 2013). Moreover, attentive, involved, and vigilant parenting also teaches children to anticipate and avoid potentially disadvantageous situations, such as affiliation with deviant peers (Simons et al., 2002; Murry et al., 2011).

Studies of academic outcomes fail to extensively capture the positive contributions of peers. Gonzales et al. (1996) reported that peers provide opportunities for students to formulate study habits, academic self-concept, academic motivation, and attitudes and perceptions regarding school importance and academic and career achievement. Further, academically oriented peers have the potential to counter the harmful effects of stereotype threat in educational settings, in turn, reducing maladaptive coping used to protect one's integrity and self-academic performance (Murry et al., 2009). In addition, prosocial peer affiliation has also been identified as a protective factor, weakening the association between racial discrimination and not only risk for underperforming academically, but also dissuading engagement in disruptive behaviors (Brody et al., 2006; Murry et al., 2009).

Collectively, we coined the term, *academic racial socialization*, to capture ways in which African American parents engage in practices to increase racial awareness, sense of racial group belongingness, pride in their history and ancestry, and the importance of setting goals to succeed in school. We contend that academic racial socialization practices may be employed by parents to socialize their children in ways to recognize and prepare for race related experiences in a manner that reduces the likelihood of consequences (e.g., harsh disciplinary strategies) that may compromise their academic success. Academic racial socialization is based on the theoretical orientation and empirical studies linking parents' ethnic-racial socialization to positive youth outcomes (Hughes et al., 2006; Murry et al., 2009). This construct specifically focuses on parenting that African Americans engage in to not only foster positive identity development in their children but to also promote academic success and lifelong success. It is worth highlighting that despite the widening academic disparity gap, limited attention has been given to identifying ways in which African American parents and families prepare their children to navigate experiences in schools that lead to academic success (Murry et al., 2009). To address this void, there is a need for prevention scientists to harness protective processes in African American families that help their children navigate interactions in schools that may be drivers of negative academic outcomes.

In sum, while school climate and social environment may perpetuate structural inequalities that contribute to academic disparities among African American youth, we hypothesize that parents and peers may serve a protective and promotive role to deter youth from succumbing to race-related school challenges. Further, results of a randomized trial demonstrated that a cluster of intervention-targeted parenting strategies, which included racial socialization plus universal parenting skills related to parent–child relationships and positive discipline, were associated with improvements in adolescent racial pride and multiple behavioral health outcomes (Brody et al., 2005; Murry et al., 2005, 2007, 2009, 2011, Berkel et al., 2022). The current study was conducted to expand on previous preventive intervention findings by testing the extent to which a family-strength based program, the Strong African American Families (SAAF) program, designed to deter risk engaging behaviors among rural African American would demonstrate efficacy in promoting academic success, through a cluster of parenting strategies, characterized as academic racial socialization.

SAAF causative model, a theory of the individual and family processes that explain the program's effects on rural African American youths' engagement in sexual risk behavior (Murry et al., 2005), is based on several theories. Bronfenbrenner and Morris (1998) and Cicchetti and Toth (1997) conceptions of the ecology of development, Zimbardo and Boyd (1999) time perspective theory, Bandura's (1997) and Barkley's (1997) theories about the development of self-regulatory mechanisms, and Gibbons and Gerrard's (1997) prototype/willingness model of adolescent health risk behavior. Specific processes were selected for inclusion in the model on the basis of Murry and Brody's prior and ongoing longitudinal research with rural African American youth and their families (Murry and Brody, 1999, 2002; Brody et al., 2004, 2005). Our causative model was based on an expectation that exposure to the SAAF curriculum would evince positive youth developmental outcomes through program-related effects on caregivers' parenting processes which we conjectured would foster youths' intrapersonal protective processes.

We hypothesize that parental academic racial socialization will foster protective processes that encourage youth to take pride in their racial identity, invest in their education, and subsequently avoid masking their academic potential as a way of coping with the negative perceptions of teachers and non-accepting peers (Murry et al., 2009). We further hypothesize that academic competence, which we conjecture represents prosocial peer affiliation, motivation to do well in school, positive attitudes about school, as well as positive relationship with teacher, will play a key role in positively orienting youth academically, thereby protecting them from academic failure and school dropout. Recognizing that race related experiences can occur early in the life of African American youth with implications for later development, we also sought to examine how exposure to protective familial factors in middle childhood would have prognostic significance for academically promotive behaviors, in spite of discriminative experiences, that in turn increase academic success as youth transitioned into adolescence. We selected these developmental stages as they have been identified as critical periods when youth are met with increased peer influence (García Coll and Szalacha, 2004) and a time when African American youth are more likely to receive expulsion or out of school experiences (Skiba et al., 2011).

Conceptual framework

To inform and guide our hypotheses, both Bronfenbrenner (1977) and Murry et al.'s (2018) integrative model for the study of stress within African American families were selected as our conceptual frameworks. The ecological model is based on an assumption that human development is impacted by dynamic relational interactions that are inextricably linked with and infused into multiple interlocking contextual systems. Humans are not only influenced by the social environments around them but are active agents employing capacities and skills to influence, as well as be influenced by environments (e.g., Tudge et al., 2009). To illustrate this process, Murry et al.'s (2018) model posits that the stress endured by African American families is, in part, a by-product of systemic racism (See Figure 1). Illuminated in this model are strengths-based, cultural assets that African Americans use to navigate socio-environmental contextual stressors, by enhancing close relationships in families, which foster positive developmental outcomes in youth. Further, this model characterizes these strengths-based, cultural assets as "ordinary magic" (Masten, 2001) which may explain how African American parents and families foster positive academic performance and aspirations in their children by assuaging the negative consequences of racialized upstream practices that have been shown to derail and hinder optimal development and adjustment potential for their children. Murry's model also acknowledges how social relationships, such as prosocial peer affiliation, can encourage behaviors that promote successful life transition, including school completion. In the following section, we provide a summary of the SAAF program, to test its efficacy in fostering academic racial socialization and in turn promoting academic success.

Overview of the Strong African American Families program

The Strong African American Families (SAAF) parenting program was developed specifically for use with rural African Americans. It is based on longitudinal, developmental research with this population and feedback from community stakeholders (Brody et al., 2004), through which proximal and malleable processes were identified in youths' immediate family contexts that facilitate academic and social competence and inhibit risk behaviors. This research indicates that powerful factors protecting children and adolescents from behavior problems originate in the family, particularly in parents' caregiving practices (Berkel et al., 2009; Murry et al., 2009). Supportive relationships with parents foster self-regulation, academic and social competence, psychological adjustment, and avoidance of alcohol use and early sexual onset among rural African American youth (Brody et al., 2006a; Murry et al., 2011). A cluster of specific protective parenting processes, which we termed *regulated-communicative parenting*, were identified in our research program, and targeted in SAAF. This cluster includes consistent discipline, parental monitoring, and open communication. SAAF also targeted youth intrapersonal protective factors, which include academic competence, social competence, and self-regulation. We expected increases in these factors to result directly from intervention attendance and to be sustained over time by changes in parenting behavior.

Strong African American Families's efficacy was evaluated in a randomized prevention trial with 667 rural African American families. The intervention's efficacy and the validity of the causative model on which it was based were supported. Families who participated in SAAF experienced increases in regulated-communicative parenting (Brody et al., 2004, 2005; Murry et al., 2005) and in youth intrapersonal protective processes (Brody et al., 2004; Murry et al., 2005). SAAF-induced effects on parenting behavior not only enhanced deterrents to adolescent risk behavior, such as negative attitudes toward risk behaviors (Murry et al., 2005), future orientation (Brody et al., 2004), self-regulation (Brody et al., 2005), and resistance efficacy (Brody et al., 2004), but also inhibited the early onset of substance use and sexual intercourse (Brody et al., 2006a) and dampened alcohol use trajectories (Brody et al., 2006b). It is not known, however, whether the program is effective in enhancing parenting strategies to reduce academic disparities. In the present study, we sought to capitalize on the implementation effectiveness of SAAF beyond the targeted outcomes and determine the non-targeted benefits of the program on other high-risk behavioral outcomes confronting African American families, such as low academic performance of African American students.

Methods

Data, participants, and procedures

In the original sample of the SAAF Program, a total of 667 families were randomly selected to participate in the study, resulting in a recruitment rate of 65%. The retention rate for families providing data in all data across time periods was greater than 84%. In 53.6% of these families, the target child was female. All families resided in Georgia, and the youth, both males and females, averaged 11.2 years of age at the time of enrollment. The families who completed the study had an average of 2.7 children. In terms of household composition, 33.1% of parents were single, 23.0% were two-parent, married households, 33.9% were married but separated from their partner, and 7.0% were living with partners to whom they

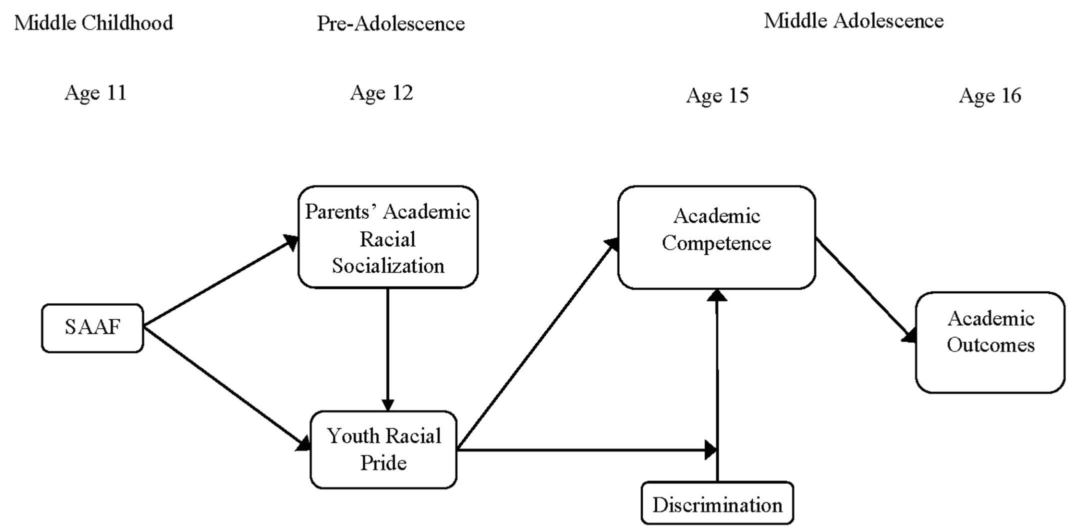

FIGURE 1
Conceptual Model (Murry et al., 2018).

were not married. Of the two-parent families, 93.0% included both target child's biological parents, with mothers representing the majority of participating parents. Caregivers/mothers' mean age was 38.1 years. Most of the mothers, 78.7%, had completed high school. The family median household income was $1,655.00 per month.

To identify pathways through which exposure to a family-based preventive intervention during middle childhood may forecast academic performance during the pre-adolescence and middle-adolescence stages, we selected data points that include baseline (Time 1; Age 11), 6 months' post-intervention (Time 2; Age 12), 48 months' post-intervention (Time 4; Age 15), and 54 months' post-intervention (Time 5; Age 16). Of the 667 families at baseline, 571 families remained in the study at Time 6, and attrition rates were similar by treatment condition (IV: 88%, Control: 82%).

Measures

Group assignment to SAAF

Random assignment in SAAF was dummy coded, with participation in the intervention group coded as 1 and participation in the control group coded as 0.

Parental academic racial socialization

An eight-item scale measure was developed using seven items from the Racial Socialization Scale (Hughes and Johnson, 2001) and one item from the General Child Management Survey (Spoth et al., 1998) to assess parents/caregivers' approaches and strategies to prepare their children to navigate race-related experiences in school settings. Examples of items include, "*I know the way that I handle racism teaches my children how to handle these situations*" and "*How often in the past month have you told your child that he/she must be better than White kids to get the same rewards because of his/her race?*," using a three-point Likert scale ranging from 1 *(never)* to 3 *(three to five times)*, $\alpha = 0.79$ across both Times 1 and 2.

Youth racial pride

During middle childhood and pre-adolescence, youth responded to an 8-item questionnaire, the Inventory of Black Identity (Sellers et al., 1997), using a 5-point Likert scale ranging from 1 *(strongly disagree)* to 5 *(strongly agree)*. Statements included "*Being Black is an important part of my self-image,*" and "*I am happy to be Black,*" with $\alpha = 0.60$ and 0.67, for Times 1 and 2, respectively.

Youth academic success

Youths' academic success consists of indicators form an adapted version of Harter's (1982) academic engagement and competence scale and affiliating with prosocial academically oriented peers (adapted from Elliott et al., 1985). For the academic orientation measure, 20 items were rated on a five-point Likert scale ranging from 1 *(Strongly disagree)* to *(Strongly agree)*. The measure was composed of four subscales—motivation to do well in school, self-efficacy completing assignments, positive attitudes toward school, and relationship with teachers—and included sample items such as, "Grades are very important to me" and "I feel very close to at least one of my teachers." Responses to the items were re-coded and summed to obtain a total score for each indicator to reflect youth academic success, with $\alpha = 0.80$ for all indicators across middle adolescence (Time 1: $\alpha = 0.85$; Time 2: $\alpha = 83$). Affiliating with prosocial academically oriented peers was measured using a 13 items scale, in which youth responded to a three-point Likert scale ranging from 1 *(all of them)* to 3 *(none of them) to items such as:* "During the past 12 months…" with a sample statement including "how many of your close friends have skipped school without an excuse?" Cronbach's α was 0.80 across data collections.

Racial discrimination

Youth rated their exposure to race-related experiences, using the 9-item Racist Hassles Questionnaire (Harrell, 1997), were rated on a 4-pt scale from 1 *(never)* to 4 *(frequently)*. Example items were, "*blamed for something or treated suspiciously (as if you have done something or will do something wrong) because of your race,*" "*treated rudely or disrespectfully because of your race*," and "*called a name or harassed because of your race*." Cronbach's α was 0.90.

Academic risk outcomes

Two indicators from the Personal Life Stressor (Holmes and Rahe), measure were used to assess academic failure and dropout vulnerability. For academic failure, youth were asked if in the past 12 months, they had failed in school on a 3-point Likert scale: 1 *(no)*, 2 *(yes)*, or 3 *(not in school)*. To measure school dropout, youth were asked, "*In the past 12 months, did you quit or drop out of school?*," using a two-point Likert scale (1 = *no*, 2 = *yes*).

Analytic plan

Study hypotheses were tested via structural equation modeling in Mplus 8.1 (Muthén and Muthén, 2018) in two separate models (see details below). To address missing data, we conducted Little's (1988) MCAR test, which demonstrated that data were likely missing completely at random ($X^2(30) = 26.16$, $p = 0.67$). Full Information Maximum Likelihood was used to address missing data (Enders and Bandalos, 2001). Nesting of individuals within clusters can result in violations of independence. Because only one of the three conditions was conducted in a group format, we determined that county was the most appropriate cluster variable. ICCs for each variable were all under 0.05, indicating independence of the data by county (Kreft and de Leeuw, 1998).

Multiple fit indices were used to evaluate the adequacy of model fit: either a non-significant χ^2 or a combination of SRMR below 0.08, RMSEA below 0.08, and/or CFI above 0.90, based on simulation studies that revealed using this combination rule resulted in low Type I and Type II error rates (Hu and Bentler, 1999). We also examined modification indices to determine whether additional paths were indicated by the data. The significance of standardized βs represent tests of study hypotheses. We used bias corrected bootstrap confidence intervals to assess the significance of the standardized indirect effects. Specifically, we tested for (a) an indirect program effect on adolescent racial pride through the enhancement of parental academic racial socialization and (b) an indirect protective role of youth racial pride in reducing risk for academic failure and school dropout through the enhancement of academic success. Mediation was considered significant if the 95% CI did not cross zero (MacKinnon et al., 2002; Fritz and MacKinnon, 2007; Taylor et al., 2008).

Results

Preliminary analyses

Parental academic racial socialization was associated with youths' racial pride at ages 11 and 12 (See Table 1). Racial pride during those developmental stages was positively associated with academic competence at age 15. All five indicators of academic competence were significantly intercorrelated (all p-values ≤ 0.001). Moreover, academic failure was positively associated with school dropout. None of the other variables were associated with school dropout. Exposure to racial discrimination at 15 years old was negatively associated with academic competence and positively associated with academic failure at 16 years old but not related to school dropout.

Test of the hypothesized model

Results demonstrated good overall model fit [χ^2 (86) = 115.01, $p \leq 0.01$; RMSEA = 0.025 (90% confidence interval, CI = 0.011, 0.036), CFI = 0.98]. Standardized βs represented tests of study hypotheses (see Figure 2). Loadings for the five indicators of the academic competence latent construct were all above 0.35, $p \leq 0.001$. We ran different models, testing alternative paths; however, none of the additional paths fit the data as well as the original hypothesized model.

Assignment to SAAF, while their children were in middle childhood, led to improvements in parents' academic racial socialization ($\beta = 0.09$, $p < 0.05$), which was consequently positively associated with youths' racial pride ($\beta = 0.15$, $p < 0.001$) during pre-adolescence. In turn, youths' racial pride at age 12 predicted increases in academic competence in middle adolescence (age 15; $\beta = 0.22$, $p < 0.001$), including motivation to do well in school, association with prosocial peers, heightened sense of efficacy to complete assignments, positive attitudes about school, and positive relationships and interactions with teachers. Exposure to racial discrimination at age 15 predicted decreases in academic competence ($\beta = -0.24$, $p \leq 0.001$), and at age 16, academic failure predicted school dropout ($\beta = 0.23$, $p \leq 0.001$). Mediational analyses demonstrated a significant indirect program effect on adolescent racial pride through the enhancement of parental academic racial socialization [$\beta = 0.15$ (95% CI = 0.006, 0.223)]; youth racial pride demonstrated a significant indirect negative association linking academic failure and school dropout mediated through academic competence [$\beta = -0.17$ (95% CI = 0.006, 0.223) and $\beta = -0.09$ (95% CI = 0.006, 0.223), respectively]. Finally, we conducted gender moderation analyses, and although there were no significant gender differences in the relationships between parental academic racial socialization and youths' racial pride, females demonstrated higher academic competence than their male counterparts ($\beta = 0.19$, $p < 0.001$) during middle adolescence. In sum, random assignment to the SAAF program directly increased parental academic racial socialization strategies, which indirectly influenced academic outcomes of their children through racial pride and academic competence enhancement, which favored daughters more than sons.

Discussion and conclusions

A plethora of studies have been undertaken to explain the widening academic gap between African American students and their White counterparts. Emerging from those studies is the conclusion that African American students are among the most vulnerable populations experiencing educational marginalization in our society (Venzant Chambers and McCready, 2011; Causadias and Umaña-Taylor, 2018; Gaylord-Harden et al., 2018). While several plausible

TABLE 1 Correlations for study variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Parental academic racial socialization-Time 1	–											
2. Racial pride-Time 1	0.08*	–										
3. Parental academic racial socialization-Time 2	0.43**	0.04	–									
4. Racial pride-Time 2	0.09*	0.32**	0.12**	–								
Academic competence:												
5. Affiliation with academically oriented prosocial peers	−0.08	0	−0.01	−0.01	–							
6. Motivation	−0.04	0.09*	−0.02	0.11*	0.30**	–						
7. Self-efficacy	−0.05	0.08	−0.03	0.12**	0.27**	0.71**	–					
8. Positive attitudes	0.02	0.07	0.04	0.03	0.33**	0.59**	0.57**	–				
9. Relationship with teacher	−0.05	0.05	−0.05	0.01	0.34**	0.61**	0.50**	0.53**	–			
10. Discrimination	0.10*	0.03	0.07	−0.03	−0.31**	−0.16**	−0.13**	−0.21**	−0.25**	–		
11. Academic failure	0.00	−0.04	0	−0.07	−0.08	−0.12**	−0.17**	−0.13**	−0.14**	0.11*	–	
12. School drop out	−0.02	−0.02	0.05	−0.01	−0.08	−0.07	−0.08	−0.09	−0.03	0.05	0.25**	–
Mean	1.89	4.05	1.93	4.17	2.62	4.30	4.07	4.04	4.16	1.40	1.36	1.05
Standard deviation	0.44	0.94	0.43	0.82	0.36	0.56	0.58	0.60	0.77	0.39	0.64	0.21

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

explanations have been offered, one school of thought is that the racialized experiences of African American students in schools situate their everyday experiences in a context in which social interactions and relationships with teachers, peers, educational policies, and practices impede aspirations, sense of belonging, performance and ultimately, school completion.

Academic disparities are often attributed to teachers' implicit racial biases and negative subjective evaluations of African American students, often associated with stereotypical images of African Americans. These negative perceptions are often met with discriminatory practices and social interactions and are thought to be contributors to disparate academic outcomes (Chin et al., 2020). While the sources of racism are structural and systemic, requiring radical changes to eliminate social determinants that perpetuate inequities (e.g., education, economics, health and health care, neighborhood and built environment, social and political contexts), African American parents are confronted with challenges to identify ways to navigate the downstream effects of racism on their children's daily lives, and engage in practices to protect their children from succumbing to adversities (Murry et al., 2009).

In the current study, we test the efficacy of the Strong African American Families program, a strength and culturally centered, family-based preventive intervention program, for its potential promise for enhancing parenting processes, namely academic racial socialization, to facilitate positive school outcomes for children. To our knowledge, this is the first empirical test of a strengths-based, culturally tailored preventive intervention designed to address racial academic achievement gap. Further, we expanded the previous findings of SAAF to concurrently consider the contributions of both parents and prosocial peers as untapped positive influencers of youth developmental outcomes, in this instance academics.

Several key findings emerged from our study. Results suggest that increases in parental academic racial socialization, for those randomly assigned to SAAF, was indirectly associated with preventing academic failure and subsequently, school dropout through its effect on facilitating youth racial pride. This finding expands studies demonstrating the powerful protective nature of parental racial and ethnic socialization practices in dissuading risk-engaging behaviors through the promotion of ethnic-racial identity (Neblett et al., 2006; Huguley et al., 2019). The relevance of the findings from the current study also adds to Byrd and Chavous' (2009) study, which demonstrated that high racial pride was a strong predictor of high GPA for African American youth, and especially for those living in low resourced communities. Despite raising their children in economically and socially racialized conditions, many rural African American families have important strengths that help their children thrive academically and become competent individuals, despite exposure to negative environments, including schools.

The urgent need for expanding this line of research, protective nature of parental academic racial socialization, is further supported as our findings revealed ways in which racial discrimination can derail African American youths' academic success. Specifically, our findings demonstrated that racial discrimination was negatively associated with all indicators of youths' academic outcomes, displaying reduced motivation to do well in school, compromised sense of academic self-efficacy, more negative attitudes toward school, and lowered sense of bonding and connection with teachers. These findings are consistent with previous research demonstrating the detrimental consequences of African American students' experiences of racial discrimination on academic outcomes (Gale, 2020; Gale and Dorsey, 2020).

Studies of academic disparities have consistently found gender differences, such that girls report greater school achievement, higher school completion, and overall higher educational attainment than males (Duckworth and Seligman, 2006; Chavous and Cogburn, 2007). However, reasons for these differences have not been fully clarified.

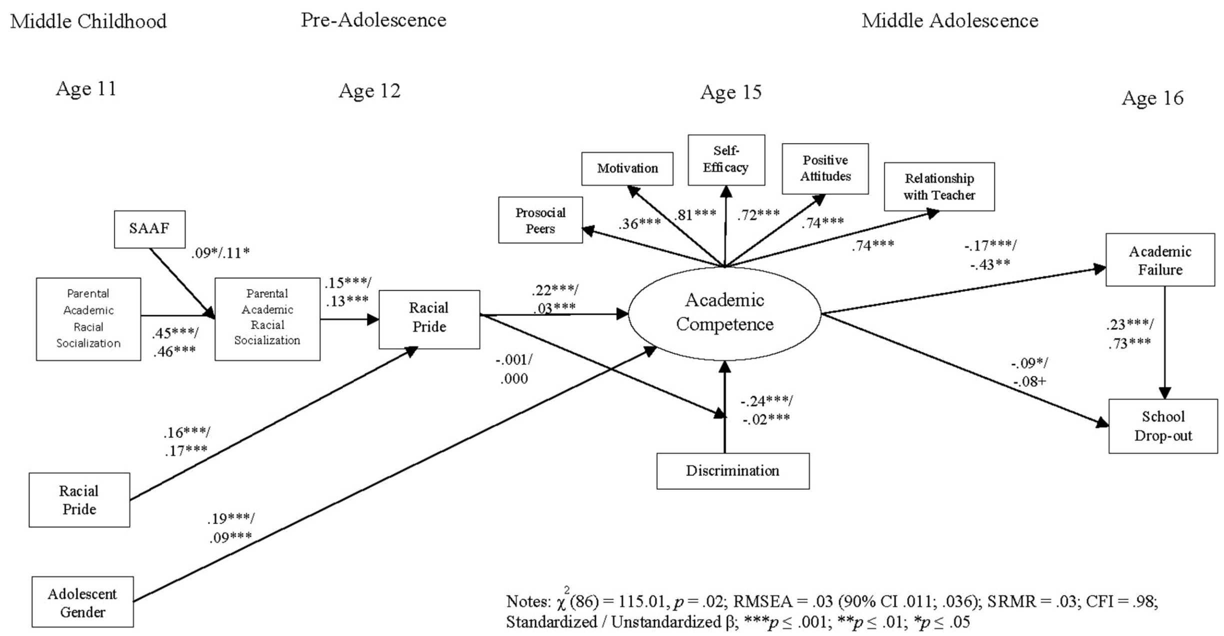

FIGURE 2
Final analytic model.

We sought to add insight on this phenomenon. Further, we also examined whether changes in males and females' academic outcomes differed across developmental stages. In terms of gender effects, moderation tests were conducted on each of our predicted paths and only one significant finding emerged. At age 11, a critical developmental and academic transitional period, African American girls scored higher on academic competence than boys. While other studies have shown similar findings, our study was designed to test theories that identify specific pathways that explain why girls outperform boys on academic indicators and what promotes change in those outcomes. Both parental academic racial socialization and racial pride were key protective mechanisms that explained these gender differences, favoring higher academic outcomes for girls. That gender differences did not emerge for the remaining paths suggests that the effects of parental academic racial socialization as a protective process against the consequences of racial discrimination for African American youths' academic outcomes are similar for males and female students. Given this, there is utility for gaining greater insight on the link between racial discrimination and academic competence through narrative descriptions of these experiences. While both male and female African American students are subjected to stereotyped perceptions and characterization by teachers (Larson et al., 2019), we offer a plausible explanation for males' academic outcomes. Specifically, studies have shown gender inequities that increase educational vulnerability for African American male students across all stages of their development (Thomas and Stevenson, 2009; Howard, 2013; Curry, 2017; Seaton and Tyson, 2019). As early as preschool, African American males are exposed to pervasive and persistent acts of discrimination, deficit framing, and are characterized as a threat to society. These perceptions also influence social interactions with teachers and peers and affect all aspects of their development, including academic outcomes. Smith-Bynum et al.'s (2014) study examining longitudinal patterns of racial discrimination of African American youth, in grades 7–10, found increased episodes of discrimination for African American males, especially in 10th grade. Continued study of these gender effects as well as identification of protective mechanisms is warranted. Our study expands Smith-Bynum et al.'s (2014) investigation by identifying and testing mechanisms that predict academic outcomes across critical developmental stages. To our knowledge, this is among the first study to examine ways in which an evidence, family, and strengths-based program can enhance processes in families to prepare African American youth for experiences that may compromise academic outcomes, with a focus on potential programmatic effects across critical developmental stages, from pre-adolescence to mid-adolescence. Findings from our study may hold promise for reducing the widening academic disparities gap, with implications for research, policies, and the design of integrative family and school-based programs specifically targeting antiracism and the enhancement of school climates and environments that are just and humane for all students.

Limitations

Although this study has many strengths, there are also limitations to note when interpreting the findings. First, while a strength of the study is the construction and testing of a newly developed measure, parental academic racial socialization, it was developed from two existing measures and as such, warrants further testing to establish internal and external validity. In addition, our measure of racial discrimination assessed overall race-related experiences, not unique to school settings. Recent studies of racial discrimination, for example, utilize more specific measures that directly measure teacher-student relationship quality, through observations that capture social interactions in context (e.g., discrimination from teachers). This approach offers opportunities to examine the nuances of discriminatory experiences in school contexts and their implications for students' development across multiple domains, including academics (Alliman-Brissett and Turner, 2010; Benner and Graham, 2013; Gale and Dorsey, 2020). Nonetheless, our measure of parental academic racial socialization was highly correlated with all targeted outcomes and racial discrimination was highly correlated with all five factors of academic competence. Academic competence predicted both academic failure, and school dropout. In addition, we acknowledge the extent to which our measure of racial pride, $\alpha = 0.60$ and 0.67, for Times 1 and 2, respectively, under-or overestimate its true reliability. Prior studies have noted that African American adolescents in more racially homogenous environments, as the families included in the current study, may have greater difficulty conceptualizing ideologies of being a minority (Scottham et al., 2008). Our findings, however, do demonstrate an increase in the reliability on this measure after exposure to the SAAF program, suggesting that the implementation of culturally tailored program that promote parents' academic racial socialization can foster racial pride and in turn contribute to youths' academic success.

Finally, some of the study pathways were concurrent, rather than longitudinal. The decision about which time points to include was driven by the higher priority and theoretical explanations underlying the SAAF program in terms of its effect in intervention-targeted parenting and youth interpersonal protective processes. That is, we conjectured that parental academic racial socialization and racial pride during preadolescence would lay a foundation to deter the negative effects of discrimination on youth during middle adolescence when problem behaviors and disengagement from school emerge.

Implications

Despite these limitations, findings from our study have several implications. First, there is a need for more longitudinal efficacy or effectiveness studies that include strengths-based, cultural assets to specify how and for whom protective mechanisms are effective for addressing academic disparities. Studies are needed to disentangle the timing and sequencing of events at various ecological levels. Further, there is a need for more mixed methods research to gain greater insight on factors and processes that explain gender differences in academic outcomes. Future studies that consider academic racial socialization as a context-specific process in families are needed as well as study designs that specifically capture the unique contribution of peers as academic influencers, beyond our proxy of measuring youths' reports of affiliating with prosocial peers.

In addition, there is a need for multi-level preventive interventions designed to address academic disparities that specifically target parents, youth, peers, teachers, and schools, as each of these systems play a central role in reducing the widening academic disparities gap. A core component of preventive interventions is addressing ways to eradicate structures, policies and practices that create, perpetuate, and maintain structural and systemic racism (Murry et al., 2018).

Our findings also have great implications for school-level policies that differentially impact the educational experiences of African American youth. School-level policies, such as zero-tolerance disciplinary strategies, are often based on implicit racial biases and subjective evaluation of students' behavior by racially biased school personnel and have disproportionately affected African American youth, contributing to high suspension and expulsion rates. This study calls for policies that ensure that schools are a place of safety that are racially and ethnically affirming social environments. Doing so will require training of school personnel in cultural humility to eradicate stereotypical thinking about African American students. Learning new ways of interaction and teaching, replacing characterizations of "unteachable," aggressive, and violent (James, 2012; Kunesh and Noltemeyer, 2019), and sassy and loud students (Cooper et al., 2022), with more affirming, accepting and promotive characterizations. These negative subjective perceptions are thought to be major contributors to disparities in school disciplinary practices and compromised school functioning, including early school leaving/dropout, regardless of gender (Leath et al., 2019). Our findings echo the urgent need to address the harm that can occur from local and state-level policies that are banning discussions of race and racism in schools and removing racial and ethnic affirming content and information from educational materials. Therefore, addressing academic disparities requires changing systems that are beyond the reach of families through the removal of upstream barriers that produce and sustain inequities.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Vanderbilt University Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

VM, CG, and MD contributed to the conceptualization and design of the manuscript. CG and VM organized the database. CG ran preliminary analyses. CB performed the statistical analysis. VM and EC wrote the first draft of the manuscript. CG and VM wrote the methods and results section of the manuscript. VM and MD wrote discussion and implications of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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EDITED BY
Parisa Parsafar,
Eunice Kennedy Shriver National Institute of Child Health and Human Development (NIH), United States

REVIEWED BY
Ashley Chung-Fat-Yim,
Northwestern University, United States
Paige Greenwood,
Columbia University, United States
Caitlin Canfield,
New York University, United States

*CORRESPONDENCE
Diane Horm
✉ dhorm@ou.edu

†PRESENT ADDRESS
Shinyoung Jeon,
Human Development and Family Science, University of Missouri, Columbia, MO, United States

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Effects of family and neighborhood vulnerability on dual language learner and monolingual children's preschool outcomes

Liz Frechette[1], Sherri Castle[1], Shinyoung Jeon[1†], Diane Horm[1*], Irving Martinez[1], Denise Vega Ruvalcaba[1] and Shawn Schaefer[2]

[1]Early Childhood Education Institute, Jeannine Rainbolt College of Education, University of Oklahoma-Tulsa, Tulsa, OK, United States, [2]Urban Design Studio, Christopher C. Gibbs College of Architecture, University of Oklahoma-Tulsa, Tulsa, OK, United States

Introduction: Research has documented that home and neighborhood contexts of children from low-income families are associated with lower cognitive and social–emotional skills than their higher-income peers. Even though over a third of young children growing up in poverty are dual language learners (DLLs), little research has examined how contextual effects differ between DLL and monolingual children. The current study examines how these two contexts, neighborhood vulnerability and family socioeconomic risk, impact executive function (EF) and social–emotional skills in DLL and monolingual preschoolers.

Methods: A secondary analysis was completed on data from two Head Start programs. A series of cross-classified models with interactions were conducted to examine the moderating role of DLL status on associations between neighborhood vulnerability and family risk and preschoolers' EF and social-emotional skills.

Results: Proficient bilingual children's EF skills were not impacted by neighborhood risks, suggesting that proficient bilingual children may have more opportunities to grow their EF skills when switching between English and Spanish regardless of neighborhood context. An unexpected result occurred for emergent bilingual children who were reported to demonstrate fewer behavior problems regardless of family risk, highlighting the importance of ensuring all DLL families have access to resources to promote their children's social–emotional skills; and teachers have the proper training to support the behaviors of children in their classroom with varying levels of English proficiency.

Discussion: Although speaking two languages may be a protective factor for young DLLs growing up in poverty, little research has examined how contextual effects differ between DLL and monolingual children. The current study contributes by examining how DLL status, especially two different DLL statuses (i.e., Proficient Bilinguals and Emergent Bilinguals), may vary as a buffer in moderating the negative associations between collective neighborhood vulnerability, individual family risk, and children's EF and social–emotional skills.

KEYWORDS

neighborhood effects, DLL, preschool-age, family effects, cognitive advantages of bilingualism

Introduction

Preschoolers from low-income families are often raised in neighborhood and home environments with elevated risks that impact their development (Jeon et al., 2014; Morrissey and Vinopal, 2018). More specifically, research has documented that home and neighborhood contexts of children from low-income families are associated with lower cognitive (Raver et al.,

2013) and social–emotional skills (Bassett et al., 2012) than their higher-income peers. Over a third of young children growing up in poverty are dual language learners (DLLs) and speak Spanish in the home (Park et al., 2017). Although speaking two languages may be a protective factor for young DLLs growing up in poverty (Kim et al., 2018; Hanno and Surrain, 2019; Hartanto et al., 2019; Grote et al., 2021; López and Foster, 2021), little research has examined how contextual effects differ between DLL and monolingual children. The current study examines how DLL status may act as a buffer by moderating the negative associations between collective neighborhood vulnerability, individual family risk, and children's executive function (EF) and social–emotional skills.

Vulnerability and risk theoretical framework

This study is rooted in the bioecological model (Bronfenbrenner and Morris, 2006), which suggests that children's development is shaped by multiple, nested contexts within their environment. The environment includes the neighborhood, classroom, and family contexts that interact with one another and influence children's development. For example, the various risks in a child's community (e.g., extreme poverty) or home (e.g., having a single parent) may influence the access to learning experiences a child has in their neighborhood or home.

The *investment perspective* and *family stress perspective* (Guo and Harris, 2000; Yeung et al., 2002; Jeon et al., 2014) also guide the objectives of this study. The investment perspective posits that the disadvantageous effects on children's development result from socioeconomic home and neighborhood risks. Due to their family's economic adversity and disadvantaged neighborhood, low-income families may lack energy, time, and financial and community resources to invest in a high-quality learning environment at home. The family stress perspective posits that the detrimental effects on children's development stem from economic burdens on the parents resulting in increased psychological distress and associated negative impacts on parenting (Masarik and Conger, 2017). Together, these theories highlight the anticipated harmful impacts of increased family risk and neighborhood vulnerability on children's outcomes.

Neighborhood environment

Collective neighborhood vulnerability, as conceptualized in this paper, includes several characteristics that together form cumulative disadvantage. These characteristics include poverty, unemployment, racial composition (a marker of racial residential segregation; Duncan et al., 2012), household structure, and the percentage of families who received subsidized care (Burchinal et al., 2002; Sampson et al., 2002; Jeon et al., 2014). A number of studies have demonstrated that children's neighborhood environment is related to their developmental outcomes (Minh et al., 2017). Neighborhoods play an essential role for young children's development because their outcomes are likely a product of their early experiences (Bronfenbrenner and Morris, 2006). Neighborhood vulnerability factors including poverty impact the quality of early experiences children have because there may be less access to high-quality developmental learning materials, activities, and interactions (Ellen et al., 2001; Sharkey and Sampson, 2017; Reynolds et al., 2019). For example, neighborhoods showing high poverty levels were less likely to have well-managed parks, high quality grocery stores, and other public places where children can visit. Research found that parks in high poverty neighborhoods were less used that parks in low poverty area and park-use was correlated with organized and supervised activities offered by the parks (Cohen et al., 2012). In other words, low-income neighborhoods often lack learning opportunities due to the inequitable distribution of environmental resources (Cohen et al., 2012; Hilmers et al., 2012; Bustamante et al., 2019). Duncan et al. (2012), noting racial segregation, found that census tracts indicating higher percentage of non-Hispanic Blacks were associated with lower open access recreational space which can promote young children's play and learning. Taken together, neighborhood risks are associated with children's lower performance on measures of cognitive (e.g., literacy, math) (Carpiano et al., 2009; Froiland et al., 2013; Jeon et al., 2014) and social–emotional skills (e.g., behavior problems) (Caughy et al., 2013; Delany-Brumsey et al., 2014; Heberle et al., 2014).

Home environment and family socioeconomic risk

Risks associated with the more proximal home and family context also play a role in shaping development (Whittaker et al., 2011). Cumulative family risk focuses on how an individual's environment increases or decreases the chance of developing negative outcomes (Jessor, 1998). For example, cumulative family risk includes characteristics that represent overall family socioeconomic status (SES) including household income, parent education level, and family structure (i.e., single-parent households). Family risk is associated with access to fewer social and economic resources, which are associated with lower academic and social–emotional success (Rimm-Kaufman et al., 2009; Crosnoe et al., 2010). Family risk has been found to be more predictive of lower child success when families fall further below the poverty line (Mistry et al., 2004). Taken together, cumulative family risk is associated with parents who are less likely to engage in behaviors at home that are supportive of cognitive and social–emotional development (Vandermaas-Peeler et al., 2009; Schmitt et al., 2015). Therefore, children who are exposed to extreme family risk may be at higher risk for lower cognitive, EF, and social–emotional skills. Accordingly, it is important to examine moderating factors that may buffer or amplify the negative effect family risk has on children's outcomes.

Dual language learners

One individual factor that may influence the effect of children's environment on their developmental outcomes is children's DLL status. Within the population of children from low-income homes, there is a growing number of young Spanish-English speaking DLLs in the United States (Baker and Páez, 2018). Previous research demonstrates that DLL children are often at higher risk than their monolingual peers for lower school success (Wildsmith et al., 2016). Due to systemic oppression, DLL children are also more likely to live in neighborhoods with concentrations of poverty and Spanish-speaking populations (Child Trends Databank, 2019). Although some researchers have theorized that exposure to Spanish may impede young DLL's developmental outcomes (Snow and Kang, 2006), a growing body of literature refutes this claim (Halle and Darling-Churchill, 2016; Kim et al., 2018; Hanno and Surrain, 2019; López and Foster, 2021). For example, the social cohesion brought about by concentrations of home language speaking neighbors may be a benefit for young DLLs (Leventhal and Shuey, 2014). Additionally, there may be benefits associated with learning two languages that are protective for DLL's developmental outcomes (White and Greenfield, 2017; Hartanto et al., 2019; Frechette et al., 2021; Grote et al., 2021). For example, Grote et al. (2021) found that bilingual preschool children from low-SES families showed cognitive advantages in several components of EF compared to their monolingual English- and Spanish-speaking peers. Hartanto et al. (2019) also found a bilingual advantage in their study using ECLS-K data for children in Kindergarten and Grade 1, reporting results that show bilingualism significantly attenuated the negative effects of SES on components of EF and self-regulatory behaviors. These findings support the Cognitive Advantage Hypothesis which posits that learning two languages produces cognitive advantages over monolingual speakers (Barac and Bialystok, 2012; Bialystok et al., 2012). Because this is an emerging area of research with gaps, inconsistent findings, and little understanding of underlying processes (Grote et al., 2021), further examination focused on young children's DLL status and associations among neighborhood vulnerability, family risk, and child outcomes is warranted.

The DLL population is a heterogenous group with varying levels of proficiency in their home and second language (López and Foster, 2021). Recently, researchers have begun to examine nuances in DLLs and subgroups have emerged including emergent bilinguals and proficient bilinguals (Lonigan et al., 2018; Francot et al., 2021; Halpin et al., 2021; López and Foster, 2021). Emergent bilinguals are less proficient in English compared to the average proficiency for their age, whereas proficient bilinguals are proficient in both English and Spanish. These two groups of DLLs may experience their environments in different ways. For example, young DLLs are often in classrooms that are primarily English-speaking (Páez et al., 2007) so emergent bilinguals could have a more difficult time engaging in classroom learning experiences and rely more heavily on their neighborhood and home environments.

Bilingual thresholds theory

The focus on proficient bilingual and emergent bilingual DLL children in this study is guided by the Thresholds Theory (Cummins and Swain, 2014). This theory posits that DLL children need a threshold level of each of their languages to benefit from the cognitive advantages associated with bilingualism (Baker and Wright, 2017). Therefore, proficient bilingual children who are able to switch between English and Spanish with more ease may benefit from a broad range of cognitive advantages (Ardasheva et al., 2017) that may buffer the deleterious effect neighborhood and home risks have on their cognitive and social–emotional outcomes.

Defining cognitive and social–emotional development in context

Executive functions

Executive functions (EF) are a domain-general, cognitive skill set that enables goal-directed behavior and includes thinking flexibly, attending to information, and mentally manipulating information (Blair, 2016). EF skills are foundational for children's learning and overall school readiness (Blair and Razza, 2007; Zelazo et al., 2016). In preschool, EF skills include resisting distractions (e.g., a talkative peer), shifting and maintaining focus on the teacher or task, and remembering to follow directions (e.g., "line up in a straight line") (McClelland et al., 2007; Bierman et al., 2008; Garon et al., 2008; Cuevas et al., 2012; Ursache et al., 2012; Ackerman and Friedman-Krauss, 2017). EF skills are important for young children to develop because they are predictors of later success both academically and socially (Best et al., 2009; Monette et al., 2011; McClelland et al., 2013; Cirino and Willcutt, 2017).

EF is a skill set that may be a strength for young DLL children (Nigg, 2000; Diamond, 2013). As discussed above, previous studies demonstrate that DLL children sometimes demonstrate better EF skills and social–emotional skills than their monolingual peers, including DLLs from low-income contexts (Halle et al., 2014; White and Greenfield, 2017; Hartanto et al., 2019; Grote et al., 2021). In general, children who are proficient and demonstrate strong skills in both languages (i.e., home language and English) tend to demonstrate higher EF skills (Melzi et al., 2017; White and Greenfield, 2017; Thomas-Sunesson et al., 2018). For example, proficient bilingual children may have more experience inhibiting one language while speaking the other (inhibition) and appropriately switching between languages (cognitive flexibility), thus strengthening their EF skills (Bialystok, 2009). More recently, attentional control has been advanced as the key mechanism supporting developmental advantages demonstrated by bilingual children (Bialystok and Craik, 2022). The extant literature identifies several potential mechanisms for why DLL children, especially those with higher Spanish and English proficiency, may demonstrate higher EF skills based on their bilingual status.

Given that EFs are a domain general skill set, not tied to a particular learning setting, and predictive of later success, it is critical to examine if the neighborhood and family environments impact EF skills. Previous studies examining how neighborhood risk is associated with EF skills have found that children living in poverty have lower EF skills than their peers (Willoughby et al., 2018) and that children in more vulnerable neighborhoods show slower growth in EF skills compared to their peers in less vulnerable neighborhoods (Wei et al., 2021). Previous studies examining family risk and EF abilities have found links between indicators of family risk (e.g., single-parent status) and children's EF inhibition skills, such that children who were from single parent households had lower inhibition (Baker et al., 2019). Other studies have found that parental education is directly linked to poorer EF skills in children (Vrantsidis et al., 2020) and theorize that parents with lower education experience more psychological distress, which may impact their ability to optimally foster their child's EF growth. However, no studies to date have examined if these relations vary across subgroups of DLL, with proficient bilinguals demonstrating less negative impact of neighborhood or family vulnerability than their peers.

Social–emotional skills

Development of positive social–emotional skills in early childhood has been linked to a number of positive outcomes ranging from physical health, later behavior, academic motivation, and employment (Moffitt et al., 2011; Jones et al., 2015; Heckman, 2018). Two social–emotional skills that young children develop are prosocial skills and self-regulation of behavior and emotion (Crane et al., 2011).

Prosocial skills include children's strengths in self-control, initiative, and attachment with adults as the antecedent conditions associated with an increase in the likelihood of positive outcomes (Crane et al., 2011). DLLs with higher prosocial skills in preschool show more rapid growth in school success into elementary school (Kim et al., 2014). Low self-regulation results in behavior problems or challenging behaviors (e.g., aggression, disruption) and is associated with lower school success (LeBuffe and Naglieri, 1991; Hartman et al., 2017). These two social–emotional skills, prosocial skills and self-regulation, are important for young children to develop because they are related to better transitions into formal schooling (Ansari et al., 2020) and later achievement (Duckworth and Carlson, 2013).

A bilingual advantage for social–emotional skills may exist. Some studies report that DLL children from low-income homes, regardless of their language proficiency in both languages, out-perform their monolingual peers on social–emotional assessments (Han, 2010; Halle et al., 2014; Kim et al., 2018). More specifically, young DLL children show stronger prosocial skills and lower behavior problems compared to their monolingual peers (De Feyter and Winsler, 2009; Galindo and Fuller, 2010; Han, 2010; Han and Huang, 2010; Luchtel et al., 2010; Winsler et al., 2014a; Hartanto et al., 2019). Yet other studies report that within the DLL group, only children who have higher proficiency in English and Spanish (e.g., proficient bilinguals) have a social–emotional advantage compared to their less proficient peers (e.g., emergent bilinguals) (Melzi et al., 2017). Therefore, depending on children's language status, there may be differential relations between neighborhood vulnerability, family risk, and social–emotional skills.

Studies examining the impact of neighborhood vulnerability indicate that living in a high poverty neighborhood as a young child is predictive of increased behavior problems (Edwards and Bromfield, 2009; Roy et al., 2014). Additionally, young children who live in more vulnerable neighborhoods show lower prosocial skills (Edwards and Bromfield, 2009). At the family level, low-income status can put a great deal of stress on families. Increased stress can result in reduced quality of the home environment, thus impacting children's behaviors (Blair and Raver, 2012). For example, poverty-related parent stress can impact their ability to provide a stimulating home environment that has ample opportunities for their children to practice their prosocial skills (Bradley et al., 1989; Hart and Risley, 1995; McClelland et al., 2000; Schmitt et al., 2015). Previous work examining family risk and children's social–emotional skills has identified a relation between single parent status, one of the family risk indicators, and young children's behavior problems (Baker et al., 2019), such that children of single-parents had more behavior problems compared to their peers from two-parent households. Finally, as parents' education level decreases, their children demonstrate more behavior problems (Sektnan et al., 2010). Although associations have been identified between neighborhood vulnerability and family risk to children's outcomes, few studies have examined how DLL status may impact these relations. Given the strengths associated with learning two languages it is critical to examine if DLL status buffers some of the negative environmental effects on their developmental outcomes.

Current study

The current study examines how two contexts (1) neighborhood vulnerability and (2) family socioeconomic risk impact children's EF and social–emotional skills. Family and neighborhood contexts are considered influential environments for the development of preschoolers because they are likely to spend most of their time in these two environments (Jeon et al., 2014). Moreover, given the need to best serve the growing number of young DLLs raised in low-income environments, this study also examines group differences among monolingual and DLL children. Specifically, the current study has three aims:

1. examine if neighborhood vulnerability and family risk are associated with EF skills. It was hypothesized that higher neighborhood vulnerability and family risk would be associated with lower EF skills (Baker et al., 2019; Vrantsidis et al., 2020; Wei et al., 2021).
2. examine if neighborhood vulnerability and family risk are associated with social–emotional skills. It was hypothesized that higher neighborhood vulnerability and family risk would be associated with higher behavior problems (Edwards and Bromfield, 2009; Roy et al., 2014; Baker et al., 2019) and lower prosocial skills (Edwards and Bromfield, 2009).
3. examine if DLL status moderates the relation between family socioeconomic risk and neighborhood vulnerability on EF and social–emotional outcomes. It was hypothesized that proficient bilingual status would moderate the relation between neighborhood vulnerability and EF skills as well as family risk and EF skills (Melzi et al., 2017; White and Greenfield, 2017; Thomas-Sunesson et al., 2018). It was also hypothesized that proficient bilingual status would moderate the relation between neighborhood vulnerability and social–emotional as well as family risk and social–emotional skills (Winsler et al., 2014b; Melzi et al., 2017).

Methods

Data sources and procedure

Data were obtained from two Head Start (HS) program evaluation studies conducted by a university research team. Both HS programs served preschoolers from low-income families and were located in an urban Midwest city in the mid-southern portion of the U.S. Data from these studies were collected between 2016 and 2019. The university's Institutional Review Board approved all procedures for these studies. Center directors, teachers, and parents provided informed consent to participate and were provided with a detailed description of what participation in the study involved.

Participants

Data were combined across the two evaluation studies for a total of 1,367 participants. As noted above, all participants were enrolled in HS and thus their families met the program eligibility requirement of having incomes at or below the federal poverty level (Administration for Children and Families, 2018). Due to a lack of addresses to identify neighborhoods, 304 children were dropped from the sample because their family homes could not be geocoded. An additional 42 children were dropped who were DLLs but had a home language other than Spanish. The final sample included 1,021 children (48% male) from 152 HS classrooms in 13 HS centers geographically dispersed across

TABLE 1 Descriptive statistics and bivariate correlations.

				Bivariate correlations							
Variable	M (*SE*)	Range	*n*	1	2	3	4	5	6	7	8
1. Family socioeconomic risk	1.81 (0.93)	0–3	1,063	–							
2. Neighborhood vulnerability	0.00 (1.00)	−1.94-2.7	1,063	0.21**	–						
3. Executive function (EF) skills	21.17 (12.73)	0–58	1,063	−0.18**	−0.14**	–					
4. Protective factors (DECA)	49.92 (9.96)	28–72	1,020	−0.11**	−0.08**	0.27**	–				
5. Behavior problems (DECA)	51.58 (9.70)	29–72	868	−0.12**	0.03	−0.23**	−0.67**	–			
6. Child sex (1 = male)	0.52 (0.50)	0–1	1,063	0.02	−0.09**	−0.16**	−0.21**	0.27*	–		
7. EF age	43.41 (6.47)	36–61	1,063	−0.23**	−0.07*	0.56**	0.09**	−0.15**	−0.01	–	
8. DECA age	41.62 (8.81)	23–61	1,020	−0.27**	−0.07*	0.50**	0.02	−0.15**	0.02	0.91**	–
9. Total time enrolled (in months)	14.90 (11.47)	0–65	1,063	−0.11**	−0.05	0.12**	0.05	0.01	0.05	0.13**	0.12**

$^{**}p < 0.01$, $^{*}p < 0.05$.

the city. Children ranged in age from 23 to 61 months (see Table 1). Children were predominantly Hispanic (37.7%) and Black (32.9%) with small percentages of White, Non-Hispanic (13.0%), and other races (16.4%). On average, children had been enrolled in their HS center for 14.92 (*SD* = 11.47) months.

Measures

Neighborhood vulnerability

Using geocoded census tract address data, HS child data were linked to U.S. Census Bureau Data (2017), which were collected at approximately the same time children in this sample were enrolled in the HS centers. Neighborhood vulnerability was modeled after previous research (Burchinal et al., 2002; Sampson et al., 2002; Duncan et al., 2012; Jeon et al., 2014). Children's geocoded census tract was linked to indicators of neighborhood vulnerability including (1) the percentage below the federal poverty line, (2) the unemployment ratio, (3) the percentage of female-headed households with children, (4) the percentage receiving public assistance, (5) the percentage of African Americans (an indicator of racial residential segregation and structural racism; Duncan et al., 2012), and (6) the percentage receiving food stamps. The percentage of African Americans was included in the measure of neighborhood vulnerability but not the percentage of Latinx given the history and current census tract data for the city where this study was conducted which shows high racial residential segregation for African Americans only. The same degree of residential segregation is not true for Latinx residents. These six indicators were summed and transformed into a z-score to create a total neighborhood vulnerability score. Cronbach's alpha of the six indicators = 0.92.

Family socioeconomic risk

Child demographic information was obtained from administrative records of parent reports at enrollment from both HS evaluation studies and confirmed through parent interviews during fall data collection. Family socioeconomic risk was estimated by summing the number of risks reported in the demographic forms (Jeon et al., 2014). The indicators included household income (dummy coded as 1 = annual income below 100% of the poverty line and 0 = annual income above 100% of the poverty line), single-parent status (dummy coded as 1 = single parent and 0 = more than one parent in the household), and parent education [dummy coded as 1 = less than an associate of arts (AA) degree and 0 = AA degree or higher].

Dual language learner status

Children's language status was determined by the parent's response during enrollment (i.e., does your child speak Spanish?). Spanish-speaking children were grouped into two DLL categories, emergent bilingual or proficient bilingual, based on their standardized performance on the Peabody Picture Vocabulary Test (PPVT) (Dunn and Dunn, 2007; Campbell and Dommestrup, 2010), an English vocabulary measure. The PPVT has a reliability of 0.92. If children spoke Spanish at home and scored more than one standard deviation below the mean (*M* = 100, *SD* = 15) on the PPVT, they were categorized as an emergent bilingual. National standard scores were used because they allow for comparison across national samples in contrast to the mean of the sample in the current study. All children who spoke only English were grouped into the monolingual category.

Executive function

EF was measured during children's first year of preschool using the Minnesota Executive Function Scale (MEFS) (Carlson and Zelazo, 2014), a standardized, adaptive, tablet-based card sort measure administered by trained research associates. Research associates administered the MEFS in either English or Spanish, based on the child's dominant language. The measure consists of seven levels of varying complexity and children are instructed (e.g., "If it's red put it here, but if it's blue put it here") to sort a variety of cards by one of two dimensions: color or shape. The MEFS has been validated on a large sample of young children including children from low-income homes (ICC = 0.93). A total score based on accuracy and response time is computed and higher scores indicate better EF skills.

Social–emotional skills

Teachers rated children's social–emotional skills on two components, Total Protective Factors and Behavior Concerns, using the Devereux Early Childhood Assessment for Preschoolers, Second Edition (DECA) (LeBuffe and Naglieri, 1991). Ratings of children's social–emotional skills were collected in the fall of the year the child enrolled in HS to get a rating of social–emotional skills before the child spent a prolonged amount of time in the preschool environment. Both DECA scales were rated by the child's teacher. Total Protective

Factors is made up of three subscales: initiative, self-control, and attachment and higher scores indicate better protective factors. Behavior concerns is a scale that reflects poor behavior and the higher the score, the worse the teacher rates the child's behavior. Reliability estimates for Total Protective Factors and Behavior Concerns are 0.88 and 0.78, respectively (Carlson and Voris, 2018).

Data analytic plan

Bivariate correlations were computed for all independent variables (IVs) and dependent variables (DVs) to inspect correlations and differences between the performance of the language status groups. In addition, covariates (i.e., age and total time enrolled) and family risk were grand mean-centered before conducting the Bayesian cross-classified models to account for the multilevel structure of the data.

Before conducting multilevel models, we conducted intraclass correlation coefficients (ICCs) for EF and social–emotional outcomes. Mplus Version 8.7 (Muthén and Muthén, 1998-2017) was used to analyze Bayesian multilevel cross-classified models for study aims 1, 2, and 3. Cross-classified models allowed for children (Level 1) to be nested within their classroom (Level 2) and neighborhoods (Level 2) simultaneously. Group differences were examined for three groups: (1) monolingual English speakers ($n = 719$), (2) emergent Spanish-English bilinguals (emergent bilingual; $n = 219$), and (3) proficient Spanish-English bilinguals ($n = 104$). Given that the models were analyzed using a Bayesian framework, deviance information criterion was used to inspect model fit where descending values indicate better fit (Spiegelhalter et al., 2002). Multi-group analysis was not diminished by unequal sample size by managing the complexity in the analysis. In addition, we used an exploratory approach which does not require an adjust p-value (Moran, 2003). This study tested multiple hypotheses rather than conducted a simultaneous test (Saville, 1990).

For the first and second aims, we examined direct paths from neighborhood vulnerability and family risks to children's EF and social–emotional skills. For the third aims, we examined moderation models including interaction effects between DLL status and neighborhood or family risks on children's EF and social–emotional skills.

Results

Descriptive statistics

Table 1 lists means and correlations for all variables. All variables were inspected for normality and all correlations were in the expected directions. Neighborhood vulnerability was negatively associated with children's EF skills and protective factors, such that as neighborhood vulnerability increased children had lower EF skills and lower prosocial social–emotional skills. Family SES risk was positively associated neighborhood vulnerability and behavior problems. Family SES risk was negatively associated with EF and prosocial skills. Therefore, as family risk increased children had more behavior problems, lower prosocial skills, and lower EF skills. EF was positively associated with protective factors and negatively associated with behavior problems. Protective factors were negatively associated with behavior problems.

Intraclass correlation coefficients (ICCs) were computed for EF and social–emotional outcomes. ICCs ranged from 16 to27% when clustering by classroom, indicating it was necessary to nest children within their classrooms. ICCs ranged from 1 to 3% when nested within the neighborhood (see Table 2). However, Moran's I, which is a measure of how dependent geographically adjacent census tract data are based on the surrounding tracts, was significant ($p < 0.05$) for all six Census data indicators, ranging from 0.29 to 0.65, indicating that children should also be clustered within their neighborhood.

Executive function models

A series of cross-classified models were run to examine the association between neighborhood vulnerability, family risk, and DLL status on EF skills. First, a model was examined where covariates (e.g., age in months, total time enrolled, sex), predictor variables (e.g., neighborhood vulnerability and family SES risk), and dummy codes for DLL status groups predicted the dependent variable, EF skills. DLL status was dummy coded so English monolingual children were the reference group. Neighborhood vulnerability was a significant predictor of children's EF skills ($b = -0.83$, $SE = 0.14$, $p < 0.01$). Family risk was not associated with children's EF skills ($b = -0.03$, $SE = 0.03$, $p = 0.16$) (see Table 3).

Language status group differences

DLL group differences emerged on EF skills. Emergent bilingual children scored significantly lower on EF skills compared to monolingual children ($b = -0.10$, $SE = 0.03$, $p < 0.01$). There were no significant differences in EF performance between proficient bilingual and monolingual children ($b = 0.03$, $SE = 0.03$, $p = 0.12$) (see Figure 1). The box plots were performed using R Statistical Software (R Core Team, 2023).

DLL interactions

Next, a cross-classified model was examined where the interactions between DLL status and neighborhood vulnerability and DLL status and family risk were entered into the model. There was a significant moderating effect of proficient bilingual status on the relation between neighborhood vulnerability and EF skills ($b = 0.07$, $SE = 0.03$, $p < 0.05$), indicating that compared to monolingual children, proficient bilingual's EF skills are not as impacted by neighborhood risk (see Figure 2). Yet, there was no significant moderating effect between neighborhood vulnerability and EF skills by emergent bilingual status ($b = 0.01$, $SE = 0.03$, $p = 0.40$). There were also no significant moderating effects of emergent bilingual status ($b = 0.02$, $SE = 0.03$, $p = 0.27$) or proficient bilingual status ($b = -0.03$, $SE = 0.03$, $p = 0.16$) on the relation between family risk and EF skills.

TABLE 2 Intraclass correlations for child outcomes.

	Classroom cluster	Neighborhood cluster
Executive function skills	0.27	0.03
Total protective factors	0.16	0.02
Behavior concerns	0.19	0.02

TABLE 3 Crossclassified model results.

	Executive function outcome model			Social emotional outcomes model					
	Executive function			Protective factors			Behavior problems		
	B	Posterior *SD*	95% CI	*B*	Posterior *SD*	95% CI	*B*	Posterior *SD*	95% CI
Covariates									
Child age	**0.57*****	0.02	[0.52, 0.60]	0.01	0.04	[−0.08, 0.07]	−0.01	0.05	[−0.11, −0.09]
Child sex	**−0.16*****	0.02	[−0.21, −0.12]	**−0.25*****	0.03	[−0.08, −0.07]	**0.29*****	0.03	[4.59, 6.61]
Total time enrolled	0.04	0.03	[−0.02, 0.09]	0.07	0.03	[.-0.01, 0.13]	−0.02	0.03	[−0.08, 0.05]
Language status									
DLL 1 (1 = EB; ref. = Mono)	**−0.10*****	0.03	[−0.15, −0.05]	−0.01	0.04	[−0.07, 0.07]	**−0.14*****	0.04	[−0.21, −0.07]
DLL 2 (1 = PB; ref. = Mono)	0.03	0.03	[−0.02, 0.08]	**0.12****	0.03	[0.07, 0.19]	**−0.17*****	0.04	[−0.24, −0.10]
Level 1 independent variables									
Family socioeconomic risk	−0.03	0.03	[−0.09, 0.03]	**−0.08***	0.04	[−0.16, −0.01]	**0.09***	0.04	[0.01, 0.18]
Level 2 independent variables									
Neighborhood vulnerability	**−0.83*****	0.14	[−0.99, −0.48]	**−0.38***	0.19	[−0.70, −0.01]	0.18	0.21	[−0.23, 0.57]

Bold values indicate statistically significant coefficients. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Social–emotional models

A series of multilevel models were run to examine the association between neighborhood vulnerability, family risk, and DLL status on social–emotional skills. First, a model was examined where covariates (e.g., age in months, total time enrolled, sex), predictor variables (e.g., neighborhood vulnerability and family risk), and dummy codes for DLL status groups predicted the social–emotional dependent variables, Total Protective Factors and Behavior Concerns. Again, DLL status was dummy coded so English monolingual children were the reference group. Neighborhood vulnerability was a significant predictor of children's Protective Factors ($b = -0.40$, $SE = 0.19$, $p < 0.05$). As neighborhood risk increased, children's Total Protective Factors decreased. However, neighborhood vulnerability was not related to children's Behavior Concerns ($b = 0.18$, $SE = 0.21$, $p = 0.21$). Family SES risk was associated with children's Protective Factors ($b = -0.08$, $SE = 0.04$, $p < 0.05$). Family SES risk was also predictive of children's Behavior Concerns ($b = 0.09$, $SE = 0.04$, $p < 0.05$).

Language status group differences

DLL group differences emerged on both Protective Factors and Behavior Concerns. Proficient bilingual children were rated as having significantly higher Total Protective Factors skills compared to monolingual children ($b = 0.12$, $SE = 0.03$, $p < 0.01$). There were no significant differences in Total Protective Factors between emergent bilingual and monolingual children ($b = -0.01$, $SE = 0.04$, $p = 0.49$). For Behavior Concerns, both emergent bilingual ($b = -0.14$, $SE = 0.04$, $p < 0.001$) and proficient bilingual ($b = -0.17$, $SE = 0.04$, $p < 0.001$) children were rated as having fewer behavior problems compared to their monolingual peers.

DLL interactions

Next, the interactions between (1) DLL status and neighborhood vulnerability and (2) DLL status and family SES risk were entered into the model. There were no significant moderating effects of DLL status on the relation between neighborhood vulnerability and social–emotional skills. There was no significant moderating effect of DLL status on the relation between family SES risk and Total Protective Factors. However, there was a significant effect of emergent bilingual status ($b = -0.10$, $SE = 0.04$, $p < 0.01$) on the relation between family SES risk and Behavior Concerns. Emergent bilingual children were rated low on Behavior Concerns regardless of their level of family SES risk (see Figure 3). The same moderating effect was not significant for the proficient bilingual group ($b = -0.03$, $SE = 0.04$, $p = 0.47$).

Discussion

The goal of the current study was to determine if neighborhood vulnerability and family SES risk were predictive of monolingual and DLL children's EF and social–emotional skills. This was the first study to examine differences by DLL language proficiency status. Neighborhood vulnerability was predictive of children's EF skills and prosocial social–emotional skills. Family risk was predictive of both social–emotional outcomes but not EF skills. There were also differences in children's outcomes based on their DLL status. Proficient bilingual children were rated as having better social–emotional skills compared to their monolingual peers. Emergent bilingual children performed lower on the measure of EF skills, yet there was no difference between proficient bilingual children and their monolingual peers. Finally, there were two significant interactions by DLL status. Proficient bilingual status moderated the effect of neighborhood

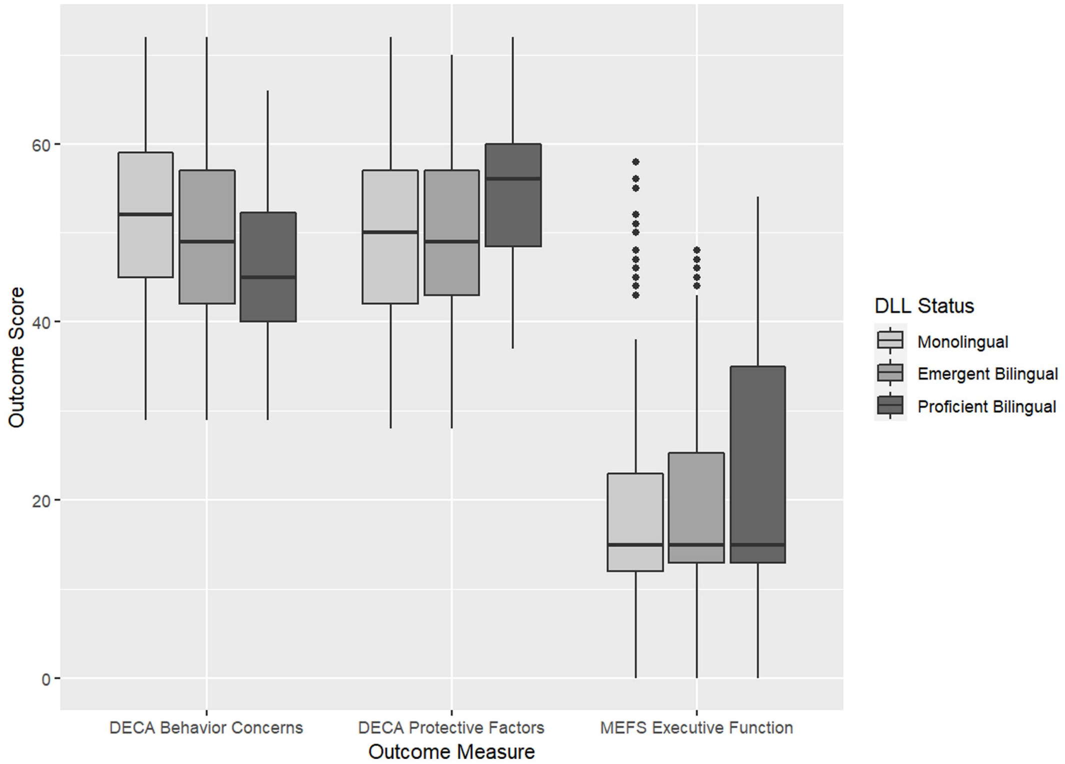

FIGURE 1
Group differences on child outcomes.

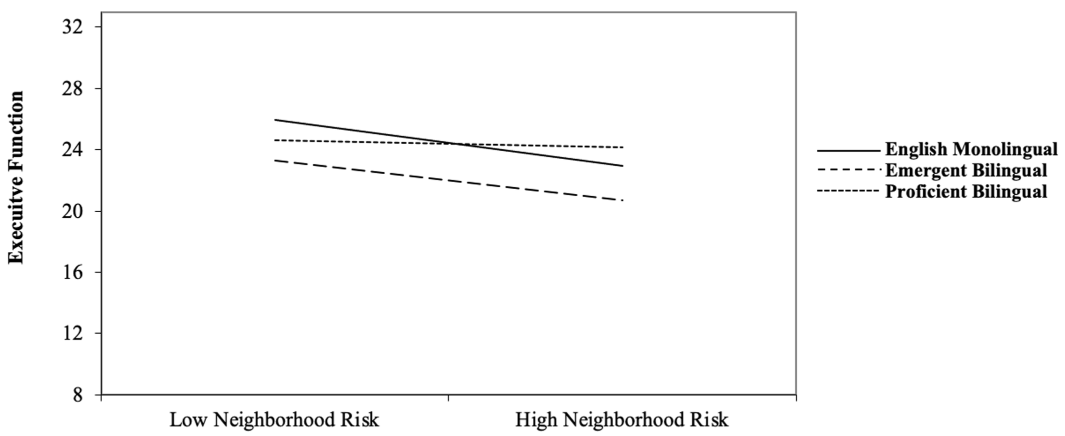

FIGURE 2
DLL moderating neighborhood vulnerability to executive function skills. All groups plotted on same graph for parsimony. Axis minimum is 1 SD below the mean. Axis maximum is 1 SD above the mean.

vulnerability on EF skills and emergent bilingual status moderated the effect of family risk on behavior problems.

The finding that higher neighborhood vulnerability was related to lower EF skills aligns with previous research (Roy et al., 2014; Wei et al., 2021) and with the investment perspective (Guo and Harris, 2000; Yeung et al., 2002; Jeon et al., 2014). Neighborhood vulnerability may be related to young children's EF skills because EF skills are a set of domain general skills that include attending to information, thinking flexibly, and holding information in working memory (Blair, 2016). Therefore, as the neighborhood environment becomes less vulnerable and less chaotic, children may have more opportunities in their neighborhood environment to engage and develop their EF skills. Future studies should examine the mechanisms within the neighborhood where children may have opportunities to engage their EF skills.

Neighborhood vulnerability may be related to children's prosocial social–emotional skills but not behavior problems because children in less vulnerable neighborhoods may have access to more resources (e.g., doctor's offices, libraries) that play a protective role in positive social–emotional development (Wei et al., 2021). Future studies

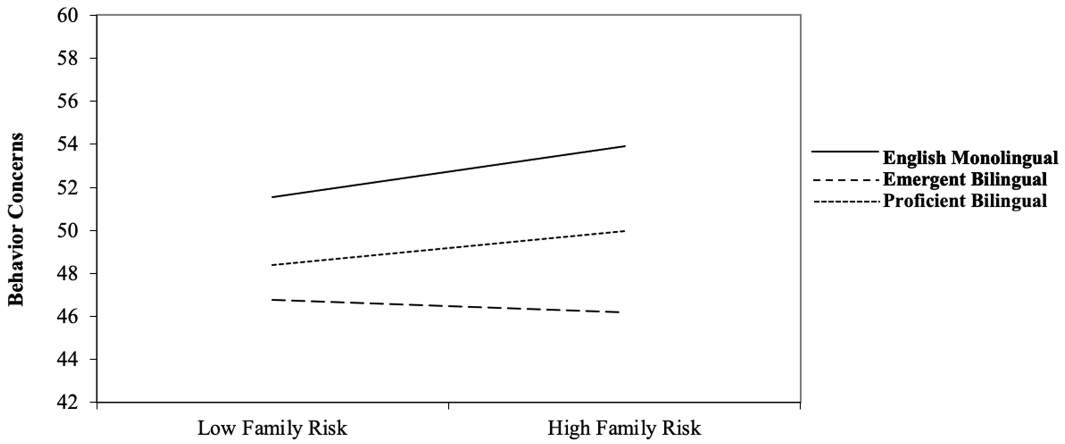

FIGURE 3
DLL moderating family risk to behavior concerns. All groups plotted on same graph for parsimony. Axis minimum is 1 SD below the mean. Axis maximum is 1 SD above the mean.

should consider the mechanisms in less vulnerable neighborhoods that help promote DLL children's prosocial skills. More specifically, it would be important to consider that aspects of the neighborhood that promote language skills and positive social interactions with others in order to identify specific processes that support development. It is possible that the neighborhood was not related to children's behavior problems because the more proximal family environment has a greater impact on young children's ability to regulate their more negative emotions like aggression.

Given that family risk was associated with social–emotional skills, this finding aligns with previous studies that have found family risk is a significant predictor of children's outcomes (Jeon et al., 2014; May et al., 2018). As family risk increased, children's prosocial social–emotional skills decreased, and behavior problems increased. These findings align with the family stress perspective (Guo and Harris, 2000; Yeung et al., 2002; Jeon et al., 2014), which suggests that negative effects on children's development are a result of economic burdens on the parents. Economic stressors could increase parents' psychological distress such as anxiety and depression which are associated with negative parenting impacting on children's social–emotional development (Masarik and Conger, 2017); research has shown that negative parenting is associated with young children's social–emotional development (Barnett, 2008; Masarik and Conger, 2017). Future studies should examine what specific supports schools can provide families with high risk to buffer the negative impact on children's behaviors.

Results suggest that proficient bilingual children have better prosocial skills while also demonstrating lower behavior problems than their monolingual peers. Additionally, being a proficient bilingual may buffer the negative effect that neighborhood risk has on children's EF skills. The moderation of proficient bilingual status on the relation between neighborhood vulnerability and EF skills suggests that proficient bilingual children, even from extremely vulnerable neighborhoods, outperform their monolingual peers on a domain-general skill set that may impact academic achievement. This may be true because proficient bilingual DLL children may consistently use cognitive skills to switch between languages, which may increase their EF skills regardless of neighborhood vulnerability.

Taken together, results suggest that there is a cognitive advantage of speaking two languages proficiently in preschool, which was evident for proficient bilingual children. Specifically, proficient bilingualism seems to function as a protective factor in the context of neighborhood vulnerability. Future studies should examine if proficient bilingual DLL status moderates the relation between neighborhood risk and other academic domains to determine the mechanism that EF plays in academic achievement. Despite the hypothesis that proficient bilingual children would perform higher on the EF measure, there were no group differences in EF skills between the three language groups. We found, however, that there was more variability in EF skills for the proficient bilingual group compared to emergent bilingual and monolingual children. Children in the proficient bilingual group were proficient in English but we did not measure their Spanish skills via direct assessment. Therefore, the DLL groups may vary widely in their Spanish language skills. There may be a subset of the proficient bilingual group that demonstrates high English and high Spanish skills (Melzi et al., 2017; White and Greenfield, 2017; Thomas-Sunesson et al., 2018) that performs better on the EF measure, but we were not able to identify this group in the current study.

Although there were promising results associated with being a proficient bilingual, the emergent bilingual DLLs did not see all the same benefits of speaking two languages. This finding aligns with the Thresholds Theory that DLL children need a certain level of proficiency in both languages to obtain the cognitive advantages associated with bilingualism (Cummins and Swain, 2014; Baker and Wright, 2017). One advantage emergent bilinguals had over their monolingual peers was they were rated lower on behavior problems. There may be several reasons for this finding. Behavior problems are emotion-related whereas EF is a cognitive skill so children may not need a threshold level of language to reduce their behavior problems. Emergent bilingual children may develop their emotional regulation skills along with their executive function skills including attention. Emergent bilinguals who are learning both languages at the same time develop their EF skills which may also affect their development of self-regulation skills and behaviors. In addition, earlier studies have demonstrated DLL children were less likely to show problem behaviors (De Feyter and Winsler, 2009; Galindo and Fuller, 2010; Han, 2010;

Han and Huang, 2010; Luchtel et al., 2010; Winsler et al., 2014a; Hartanto et al., 2019). An alternative explanation for emergent bilingual children's lower behavior problems is related to teachers' opportunity and experience to observe and children's potential behavior. As emergent bilingual children are developing their English skills in the classroom, they may have fewer opportunities to interact with their English-monolingual peers in majority English speaking classrooms, which may lead to fewer teacher observed behavior problems. Emergent bilingual children may also learn the routines and transitions of the preschool classroom and may be able to follow the rules without causing disruption because they do not truly understand the language interactions as they simply follow routines and rules (Erdemir and Brutt-Griffler, 2022). Teachers may then, consequently, observe fewer behavior problems in emergent bilingual children because they are passively engaged in the classroom and because teachers may not facilitate language interactions between emergent bilinguals and their peers (Gort and Pontier, 2013). Future studies should examine emergent bilingual children's behavior in classrooms that speak majority Spanish and determine how both languages can be used in the classroom to help support emergent bilingual DLL children's interactions.

It is important to note that the results of this study are couched in the sociocultural context of the United States. In this context, there is substantial overlap with socioeconomic status and dual language learner status. Due to systemic oppression, DLLs who are first or second generation immigrants have legal barriers to accessing many supports, and later generation immigrants often continue to face systemic inequities. Families in which the parents have limited English proficiency may face additional barriers to accessing high quality neighborhoods, learning opportunities, or other supports to enrich their children's development. Additionally, the DLLs in the current study come from a city with a relatively homogeneous group of DLLS who are primarily Spanish speaking which presents one type of context that may vary in other parts of the country. Finally, the city in which these participants live remains highly segregated and most schools operate in an English immersion model, highlighting the numerous layers of oppression experienced by these children on a daily basis.

Strengths and limitations

The current study contributes information to the debate regarding bilingual advantage—if bilingualism enhances cognition or other developmental areas—and offers several strengths. Unlike many previous studies, the sample is large with over 100 participants per group. A second strength is that the focus includes the child at the individual level and expands the scope to include both family and neighborhood contexts. A third strength is that both cognitive and socio-emotional skills were examined. Taken together, these strengths position this study to contribute information that is relevant for future research as well as practice and policy.

Despite these strengths, there are several limitations to acknowledge. First, our use of existing data produced some limitations. For example, we did not have access to direct assessments of DLL children's Spanish skills. Therefore, we do not have information about the variations among DLL children in Spanish proficiency. Future studies should examine how proficiency across both English and Spanish moderates the relation between neighborhood vulnerability and/or family risk to EF and social–emotional outcomes. Additionally, the data used in this study was cross-sectional so children's language skills were not examined longitudinally over time. As language is a rapidly developing skill in early childhood it is possible that over time DLL children move from the emergent bilingual profile to the proficient bilingual profile or vice versa. Future studies should examine these research questions longitudinally to determine antecedents to DLL children's positive development. Finally, given U.S. Census data are collected every 10 years, the match to the timeframe of the child dataset was approximate.

Classroom level variables were not investigated in the current study. Future studies should design evaluations to determine if classroom quality or support for Spanish home language in the classroom impacts the interactions between DLL status, neighborhood vulnerability, family SES risk, and developmental outcomes. Finally, children in this study were all from the same region of the U.S. which may not be representative of the U.S. population, so future work should replicate this with DLL children in various areas of the country, specifically in more Spanish speaking communities.

Conclusion

In sum, this study investigated if neighborhood vulnerability and family SES risk were associated with children's cognitive and social–emotional outcomes and the moderating role of DLL status. It extended prior research by examining how variations in DLL language proficiency impact the various environmental risks to development. Consistent with the Bilingual Threshold theory and the Cognitive Advantage Hypothesis, there were several benefits of being a proficient bilingual including better social–emotional skills compared to their monolingual peers. Proficient bilingual children also saw cognitive advantages when their EF skills were high regardless of the neighborhood environment risks they were exposed to, suggesting that proficient bilingual children may have more opportunities to grow their EF skills when switching between English and Spanish regardless of their neighborhood context. A somewhat unexpected result occurred for emergent bilingual children who were reported to demonstrate fewer behavior problems regardless of family risk, highlighting the importance of ensuring all DLL families have access to resources that help promote their children's social–emotional skills and ensuring teachers have the proper training to support the behaviors of children in their classroom with varying levels of English proficiency.

Data availability statement

The datasets presented in this article are not readily available because consent specifies data are only available to the research team. Requests to access the datasets should be directed to DH, dhorm@ou.edu.

Ethics statement

The studies involving humans were approved by the University of Oklahoma Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this secondary data analysis from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

LF, SC, SJ, DH, and SS contributed to the conceptualization and design of the study. LF, SJ, DV, and IM organized the database and cleaned datasets. LF and SJ performed the statistical analysis. LF wrote the first draft of the manuscript. SC wrote sections of the manuscript. DH and SJ finalized writing of manuscript and responded to requests for revisions. All authors contributed to the manuscript revisions, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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