Spatial Scale and Developmental Timing of Neighborhood Context and Child Cognitive and Non-cognitive Development *

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Children's cognitive and non-cognitive development varies by race, ethnicity, and class, and is predictive of adult health, social, and economic outcomes. Individual and family-level factors are important in child academic performance, but residential neighborhood may represent an important, policy-relevant, contributor to academic outcomes and disparities. In this paper, we use the Early Childhood Longitudinal Survey Kindergarten cohort of 1998, to estimate the relationship between residential environmental poverty concentration and child cognitive and non-cognitive developmental outcomes from kindergarten through 8th grade. We focus on whether residential environment affects child outcomes differently by age, by spatial scale of neighborhood measure, and whether racial disparities in outcomes are explained by residential environmental poverty. We find modest evidence for residential contextual effects on children at younger ages, with some variation by spatial scale and outcome. Neighborhood context is dynamic and multidimensional and predicts child cognitvie and non-cognitive outcomes in complex ways.

Keywords: Child development, neighborhood effects, spatial scale

Background

Early childhood cognitive and social-emotional (non cognitive) development are important determinants of life course social, economic, and health outcomes (Conti & Heckman 2010, Heckman 2006, Ritchie & Bates 2013, Hernandez 2012). Predictors of child development including optimal birth outcomes, quality of parenting attachment, and early childhood education are associated with favorable adult outcomes including reduced likelihood of felony arrest, increased income, increased likelihood of being insured, and higher attained education (Ekeus et al. 2010, Reynolds 2011). These benefits accrue through a combination of children's early development of cognitive abilities (e.g. readiness for academic success in math and reading), and through non cognitive work habits and skills of social and emotional interaction (Farkas 2003, Heckman 2006, 2008).

Economic and racial disparities in cognitive and non cognitive development are apparent early in life (Hillemeier et al. 2009), and larger racial and economic gaps are predicted by lower maternal education (Hanson et al. 2011), fetal insults including being born preterm (Richards et al. 2015, Williams et al. 2013), and lower family socioeconomic status (Mollborn 2016). Dynamics of early childhood cognitive and non-cognitive development are therefore important for the life course outcomes of individual children, but also because disparities in early life developmental skills may be important pathways for the production of racial and economic disparities in adult social and health outcomes, and as mediators of trans-generational reproduction of social stratification (Sharkey & Elwert 2011).

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Bronfenbrenner's bio ecological model of human development provides insight into the production of socially-stratified developmental and academic success (Bronfenbrenner 1979, Kramer et al. 2017). One core feature of the bio ecological model is that the driver of individual children's development results from interactions between the child and the persons, objects, and symbols in their experienced environment. These *proximal processes* become increasingly varied and complex as the child grows. For instance in infancy, feeding, parental attachment, and care giving constitute important relational processes. However as the child ages into a toddler and then pre-schooler, the proximal processes stimulating the child widen to include more people (familial and non-familial), and more varied stimuli and environments such as healthcare or daycare. These *proximal processes* vary by family socioeconomic status including variation in parenting style, cognitive stimulation, housing quality and safety, and overall child health (Guo & Harris 2000). Another feature of the bio ecological model is the nested interactions between child and the experienced environment, which includes not only by the micro environment (e.g. parent-child interaction, family), but the meso- and macro-environments including neighborhood institutions (e.g. schools) and social processes (Kramer et al. 2017).

The importance of each of these nested environments on child cognitive and non-cognitive outcomes likely varies with developmental stage. On the one hand, Bronfenbrenner's model may suggest that child-caregiver relationship or proximate family and household environment are the most relevant environments early in life. Broader residential (e.g. neighborhood) environments may become more salient only as children enter school and have increased exposure to and interaction with the people, relations, and institutions of their residential environments. Alternatively, some *life course* models highlight the *critical and sensitive windows* of development – including infancy and early childhood – as periods of heightened sensitivity to environmental insults (Russ et al. 2014, Kuh et al. 2003). In this perspective, any socially toxic effects of the residential environment might be more evident in pre-school or early elementary ages, and less so in upper elementary and middle school ages.

Scholarship from fields interested in spatial and social stratification complement the bio ecological developmental and life course frameworks by incorporating theory and measures of urban ecosystems, asking whether there are important and identifiable *neighborhood effects* on child cognitive and non-cognitive outcomes (Sastry 2012, Sampson et al. 2008, Crowder & South 2003, Leventhal & Brooks-Gunn 2000, Brooks-Gunn & Duncan 1997). Residential neighborhoods represent the physical, social, and relational environments that anchor family' (and children's) opportunity structures (Osypuk et al. 2009, Osypuk & Acevedo-Garcia 2010). These experienced opportunity environments represent a developmentally salient social context for child and family. For example Sastry & Pebley (2010) summarize four mechanisms by which residential environments could affect child cognitive development: *i)* neighborhood socioeconomic status predicts the quality of institutions including schools and educational opportunity; *ii)* neighborhoods characterized by concentrated poverty may also experience heightened crime, producing stress and associated parenting responses aimed at child safety over cognitive development; *iii)* neighborhoods provide non-familial socialization and social control, and offer children exposure (or lack thereof) to adults who value and model cognitive and non-cognitive skills; and, *iv)* the dominant language and language-use patterns of the residential environment may influence child readiness for academic success.

However, much of the extant literature examining the role of place and child development has been limited by cross-sectional study design, varied measures of neighborhood environment, and arbitrary definitions of how to operationalize the 'neighborhood'. For example, treating places as discrete administratively-defined units which are static through time, independent of each other, and only affecting individuals' health through a unidirectional trickle-down process limits our understanding of how place matters (Entwisle 2007, Matthews & Yang 2013, Matthews & Parker 2013, Matthews 2008, Sharkey & Faber 2014). In particular, the conventional reliance on a single spatial scale to define the 'local' environment (e.g. the census tract) presumes that the theoretically relevant process is fully measured at that scale. However, borrowing from ecology, the organization of social processes may be distinctly different at micro scale as compared to a macro scale (Krieger 2011). Reardon, et al (2009) describe the spatial granularity of residential segregation using multiscale measures, observing that the context of small pockets of segregation may be distinct from places with widespread segregation.

In sum, child cognitive and non-cognitive outcomes are a product of complex multileveled processes. Population disparities – racial, ethnic, and socioeconomic – in academic success may be a function of the spatially-stratified environments produced by residential segregation, which constitute the context for children and their families at different stages of development. However many gaps in our understanding of the contribution of residential context to child developmental outcomes. Paraphrasing Sharkey & Faber (2014), we do not only care *whether* residential environments affect children, but *where*, *when*, *why*, and *for whom* does residential context matter? In this paper we use the Early Childhood Longitudinal Study kindergarten, 1998 (ECLS-K) cohort to begin to address some of these gaps. Specifically, we estimate the association between *neighborhood poverty* and four outcomes, *math* and *reading* scores (cognitive), and *self-control* and *interpersonal* skills (non-cognitive). We focus on life course timing and spatial scale of exposure to concentrated poverty, asking three questions:

1. Does the association between residential environmental poverty concentration and child outcomes vary by the age at which they are experienced among Black and White children?
2. Does the association between residential environmental poverty concentration and child outcomes vary by the spatial scale at which residential environmental poverty is measured?
3. Does residential poverty concentration explain the magnitude of the Black-White disparity in child outcomes ?

Methods

Population

The ECLS-K is a nationally-representative, multistage, complex probability sample of 21,356 children entering public or private kindergarten in 1998-99, and followed up in first, third, fifth, and eighth grades. Children who moved between waves were sampled for continued followup, and design weights were calculated for each wave to account for non-sampled movers and non-response or loss to followup. There were 9,358 children followed through 8th grade. School, teacher, parent, and child assessment instruments provide direct and indirect measures of cognitive and non cognitive development, and assess family and social environment at each study wave. For this report, we use only cross-sectional weights. Census tract of residence is measured at each wave and forms the starting point for defining children's experienced residential environment (see detail below).

ECLS-K was sampled to provide analytically adequate sample sizes of racial and ethnic minority populations, including over-sampling Asian and Pacific Islander children. However, given the relatively high dimensionality of our 4 outcomes, 4 spatial scales, and 5 waves of follow-up, for this report we restrict our analysis to non-Hispanic Black and White children. These are the largest two racial-ethnic sub-groups in ECLS-K, and represent an important range of residential environments and cognitive outcomes.

Variables

Measures of cognitive outcomes. Direct cognitive outcomes were measured with standardized assessments in math and reading in each wave of follow-up (Kindergarten, 1st, 3rd, 5th, and 8th grades). Standardized scores measure performance relative to peers, with a mean T-score of 50 (SD 10) for each assessment. While the item-response theory scores are generally more appropriate for cross-sectional comparisons, the standardized T-scores are ideal for longitudinal assessment of increasing or decreasing gaps between groups in mean performance.

Measures of non-cognitive outcomes. Non-cognitive measures were derived from an adaptation of the Social Skills Rating System (Gresham & Elliot 1990), a teacher-completed evaluation of each student's internalizing & externalizing behaviors, interpersonal skills, and self-control. For the current report, we include the self-control and interpersonal skills sub scales. The self-control scale was composed of questions posed to teachers about the degree to which the study child respected the property rights of others, accepted peers' ideas for group activities, and responding appropriately to pressure from peers. The interpersonal scale gauged the child's ability to join in play easily, make and keep friends, and comfort or help others.

Neighborhood contextual measures. There are numerous possible contextual measures to characterize the residential neighborhoods of children. We initially focus on four distinct (albeit interrelated) measures including area percent black (measure of local racial composition and indirect indicator of residential segregation); percent adults over 25 with college degree and percent adults over 25 without high school degree (markers of area human capital); percent of families below the federal poverty line (local indicator of spatial poverty concentration). For the current report, only results for area-based poverty levels captured as the proportion of families living below the federal poverty line within each census unit.

To measure each of these attributes of the child's residential context, we adapt the multiscale approach proposed by Reardon et al (Reardon et al. 2008, Lee et al. 2008) for measuring spatial residential racial segregation. Specifically, we quantify *'egocentric'* measures of each indicator using four spatial scales defining the local context. Egocentric suggests the measure is the area surrounding a central focal locale (e.g. one's own residence), and the measures refer to a process by which small area counts (e.g. US Census block groups, which are smaller than census tracts were used in our case) are converted to a continuous spatial surface population density. The continuous spatial surface is composed of pixels representing the density of families in the numerator, and in the denominator, of the calculation of poverty percent. From these population surfaces, kernel density functions are applied to summarize and smooth the *mean* value of the target parameter (e.g. density of poor households) inversely weighted by the distance from a focal index location. The *egocentric poverty concentration* is calculated by dividing the kernel density surface for poor households, by the kernel density surface for all households for whom poverty status was determined.

All estimations were repeated with kernel bandwidths of 2-, 4-, 8-, and 12-km to represent a series of definitions of 'local' ranging from areas smaller than the average census tract, to those as large or larger than the average urban high school enrollment zone (Fowler et al. 2016, Kramer et al. 2010). Rather than presuming that one of these scales is more or less 'correct', we treat spatial scale as a distinct dimension of the dynamic process by which people and places intersect. Small-scale measures best represent the areas immediately surrounding the index location, whereas larger-scale measures identify sub-regions of cities patterning the broader geography of opportunity proximate to children and their families. In ECLS-K, census tracts are captured at all waves except 5th grade; we extract the poverty concentration value for the centroid of each respondent's census tract as their measure of 'neighborhood' context at that point in time, under competing definitions of the spatial scale or size of 'local'.

Other covariates. In addition to the core analytic variables, we include covariates that may predict differences in residential environment and/or cognitive outcomes. Child *age* at time of each survey wave, and child *gender* are included. In addition *family structure* (one-parent; two-parent; other), and residential *rural-urban status* were included as each might be associated with residential context and child outcomes. *Family socioeconomic position* was operationalized with a composite variable created by ECLS-K that incorporates parental education, occupation, and income. We used a categorical version of this measure, where continuous values are divided into quintiles.

Analytic strategy

The overarching analytic strategy is to fit a series of linear regression models with *poverty concentration* as the primary predictor of interest, and each of the four *cognitve* or *non-cognitive* measures as the outcome of interest. Models are all adjusted for age, gender, family structure, socioeconomic position, and residential rural-urban status.

The first dimension concerns the patterns of association between residential contextual poverty concentration and outcomes at different ages, or waves of follow up. Here we focus on whether poverty associates more or less strongly with cognitive and non-cognitive outcomes in early elementary schools (e.g. kindergarten and 1st grade), in later elementary schools (e.g. 3rd and 5th grade), or in middle schools (e.g. 8th grade). For this paper, these questions are answered with wave-specific cross-sectional associations, although in future analyses within-child growth trajectories will be considered to more fully take advantage of the longitudinal nature of the study.

For the second dimension of interest, we will vary the version of the predictor of interest, poverty concentration, by considering children's residential poverty measured using 2km, 4km, 8km, and 12km-bandwidth kernel density estimations of local poverty rates. In addition to each spatial scale, we will also consider the ratio of poverty using 12km bandwidth kernels to 2km bandwidth kernels. This ratio measure is similar to the *spatial granularity* of residential segregation described by Reardon, et al (2009). A granularity ratio of 1.0 suggests that the poverty concentration in a broad region defined by the 12km-bandwidth kernel density estimate is equal to the poverty concentration at a much more local 2km kernel definition of local. In contrast granularity ratios >1 suggest that regional poverty concentration is greater than local poverty concentration (e.g. the small scale local environment is better off than the surrounding area). Ratios <1 suggest that poverty concentration is lower in the broader region than it is in the smaller residential area.

Finally, we evaluate the degree to which the Black-White gap in child cognitive and non-cognitive outcomes is attenuated with control for residential contextual poverty concentration at various spatial scales, and ages.

All models are fit accounting for complex sample design and wave-specific survey weights using the `survey` package in R (R Core Team 2018).

Results

Describing places

The multiscale kernel density egocentric measures of poverty concentration were carried out for all areas in which ECLS-K children ever lived. For all such places, there is similar *mean* poverty concentration across all egocentric scales, but there is wider interquartile range for smaller areas, suggesting there is greater heterogeneity in poverty concentration using smaller definitions of local areas (e.g. 2km), than there is for larger definitions (e.g. 12km) (see **Figure 1**).

The granularity of poverty measures is quantified as the ratio of poverty concentration from a 12km as compared to 2km bandwidth kernel density estimation. As a ratio it is skewed on the natural scale, but symmetric on the log scale (see **Figure 2**). Most places have relatively similar poverty at both scales, but there is a variability from lower ratios (larger areas have *less* poverty than the smaller areas around each home), to higher ratios (larger areas have *more* poverty than the smaller areas).

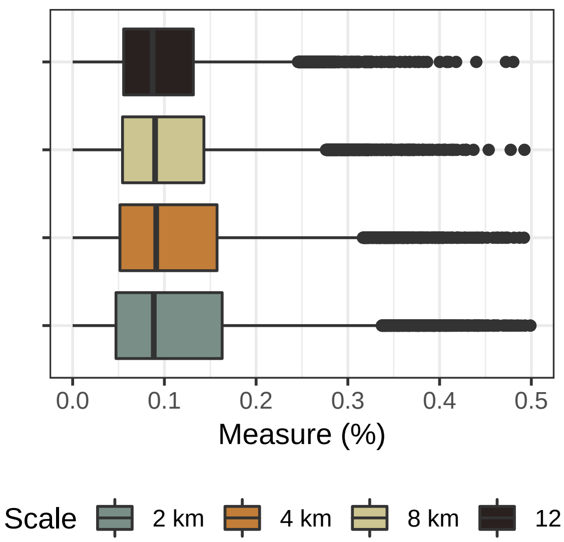

Figure 1: Distribution of egocentric measures by spatial scale

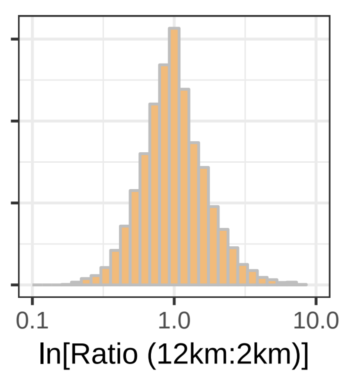

Figure 2: Granularity of measures: Distribution of ratio of 12km:2km scale measures

Describing people

The distribution at baseline (e.g. in kindergarten) of children's demographics, cognitive and non-cognitive measures, rural-urban status, and multiscale residential poverty concentration are summarized in **Table 1**, stratified by quintiles of local (2km) poverty. While age and gender do not vary meaningfully by quintile of local poverty concentration, children living in high poverty (Q5) were more likely to come from single-parent families of lower socioeconomic position, as compared to children living in lower poverty residential context (e.g. Q1-Q4). While 37% of children in the highest quintile poverty neighborhoods were non-Hispanic Black, only 4.7% of children in the lowest quintile poverty neighborhoods were Black. In general math and reading scores were inversely related to poverty concentration (lower scores for children in neighborhoods with higher poverty), and non-cognitive outcomes of teacher-rated child self-control and interpersonal skills were lowest for children living in the highest poverty neighborhoods.

Children living in neighborhoods at the lowest quintile of poverty using the 2km definition of 'local' tended to also live in broader regions with quite low poverty (e.g. 3-5% poverty across spatial scales)

Table 1: ECLS-K Respondents, Wave 1

	Poverty Q1 (low)*	Poverty Q2	Poverty Q3	Poverty Q4	Poverty Q5 (high)	p-value
Weighted n	688830.7	661533.3	688229.5	662314.8	696502.3	
Female (%)	48.4	48.1	48.8	49.1	50.1	0.586
Age (mean (SD))	5.72 (0.36)	5.71 (0.36)	5.71 (0.36)	5.71 (0.37)	5.68 (0.38)	0.067
Family Structure (%)						<0.001
Two parent	88.4	83.8	78.3	68.9	56.4	
One parent	10.9	15.6	20.2	29.1	40.1	
Other	0.7	0.5	1.6	2.0	3.5	
Family socioeconomic position (%)						<0.001
Q1 (low)	3.8	8.3	12.7	26.1	43.1	
Q2	10.3	18.3	20.8	24.6	24.4	
Q3	16.8	20.8	23.4	22.4	17.4	
Q4	27.1	25.9	22.6	16.0	10.0	
Q5 (high)	42.0	26.7	20.5	10.9	5.1	
Race (%)						<0.001
White, non-Hispanic	82.1	78.3	64.5	45.7	20.6	
Black, non-Hispanic	4.7	6.9	10.8	21.8	37.2	
Hispanic	7.6	9.5	18.6	25.8	36.8	
Asian	2.8	2.9	2.8	2.6	2.6	
Other	2.8	2.5	3.4	4.1	2.8	
Reading Score (mean (SD))	54.17 (9.58)	51.72 (9.77)	50.61 (9.98)	48.32 (9.62)	46.41 (9.05)	<0.001
Math Score (mean (SD))	54.82 (8.97)	52.42 (9.46)	50.91 (9.80)	48.16 (9.75)	45.49 (9.22)	<0.001
Self Control Scale (mean (SD))	3.18 (0.60)	3.14 (0.60)	3.09 (0.61)	3.04 (0.63)	2.95 (0.63)	<0.001
Intpersonal Scale (mean (SD))	2.41 (2.77)	2.47 (2.60)	2.51 (2.43)	2.40 (2.56)	1.92 (3.27)	<0.001
Rural-Urban continuum (%)						<0.001
Large City	7.5	9.3	12.8	23.0	43.2	
Mid-size City	13.4	16.6	25.2	25.2	26.2	
Large Suburb	59.2	36.8	32.1	22.8	11.5	
Mid-size Suburb	9.8	11.5	11.1	7.5	3.4	
Large town	0.2	4.3	3.5	1.5	3.3	
Small town	4.0	8.7	7.6	10.1	6.7	
Rural	5.9	12.9	7.8	9.8	5.7	
Poverty (2km) (mean (SD))	0.03 (0.01)	0.06 (0.01)	0.09 (0.01)	0.15 (0.02)	0.28 (0.09)	<0.001
Poverty (4km) (mean (SD))	0.03 (0.01)	0.06 (0.02)	0.09 (0.02)	0.14 (0.03)	0.25 (0.09)	<0.001
Poverty (8km) (mean (SD))	0.04 (0.02)	0.07 (0.02)	0.09 (0.03)	0.13 (0.04)	0.21 (0.08)	<0.001
Poverty (12km) (mean (SD))	0.05 (0.02)	0.07 (0.02)	0.09 (0.03)	0.12 (0.04)	0.18 (0.08)	<0.001
Pov Granularity (12km:2km) (mean (SD))	1.27 (0.24)	1.12 (0.23)	0.98 (0.21)	0.86 (0.20)	0.70 (0.20)	<0.001

Note:
All values are weighted for complex survey design.
* Poverty quintiles derived from 2km kernel density estimation

Does poverty-outcome association vary with age?

To examine the age-specific association between residential environmental poverty concentration and child cognitive and non-cognitive outcomes, we summarize the β coefficient from regression models, which represents the change in each child outcome contrasting the highest versus lowest poverty concentration using a 2km egocentric measure, adjusting for covariates (see **Figure 3**). For example looking at the bottom two panels of Figure 3 representing results for math and reading outcomes, *increasing poverty* is associated with *lower math and reading* scores for the youngest children, but is not associated with math or reading scores for children after the first two study waves. The top two panels represent the non-cognitive teacher-rated scales (only reported through 5th grade). For interpersonal skills, the youngest children (e.g. in kindergarten) again have the strongest associations with residential poverty, although the direction of the association varies by child race. For Black children in kindergarten, increasing poverty is associated with *lower* scores on the interpersonal scale, but for White children poverty is associated with *higher* scores on the interpersonal scale. There is little evidence for association between poverty and interpersonal scores for older children, nor for the association of poverty and self-control at any age.

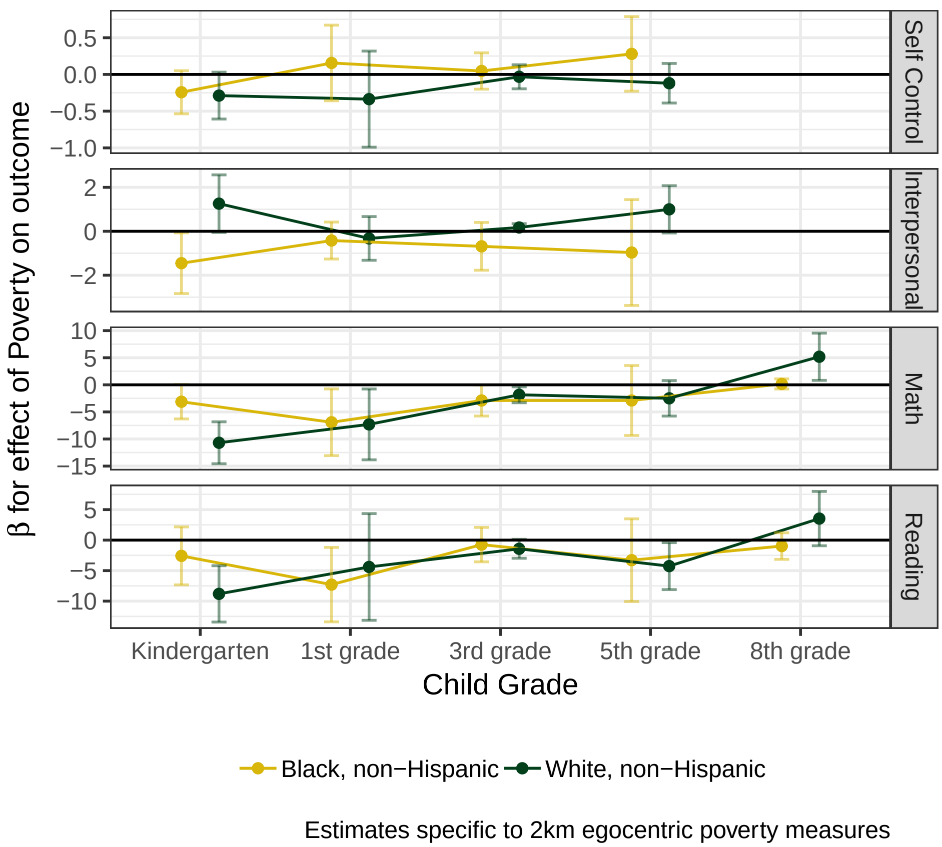

Figure 3: Model estimates of poverty-outcome association by child grade

Does poverty-outcome association vary with spatial scale of residential environment?

This question focuses on whether the patterns of association between children's environments and their cognitive or non-cognitive outcomes vary as a function of the spatial scale at which residential context is measured. As seen in **Figure 4**, the x-axis now represents increasing scales of egocentric poverty concentration measurement ranging from the smallest 2km 'local' definition to a broader 12km 'regional' definition. Model β coefficients are once again presented for each outcome, and separately by child race. There is only limited evidence for scale dependence in the patterns of association. For example, for the cognitive outcomes of math and reading (bottom two panels), there is a modest decrease in the strength of the association between poverty and outcomes with increasing scale, but only for children in kindergarten and first grade. For non-cognitive outcomes, once again the only scale-trend is evident in the first two waves. Teacher-rated interpersonal scale scores are more strongly associated with poverty when poverty is measured at large scales (e.g. 12km) as compared to small scales, although the direction differs by child race.

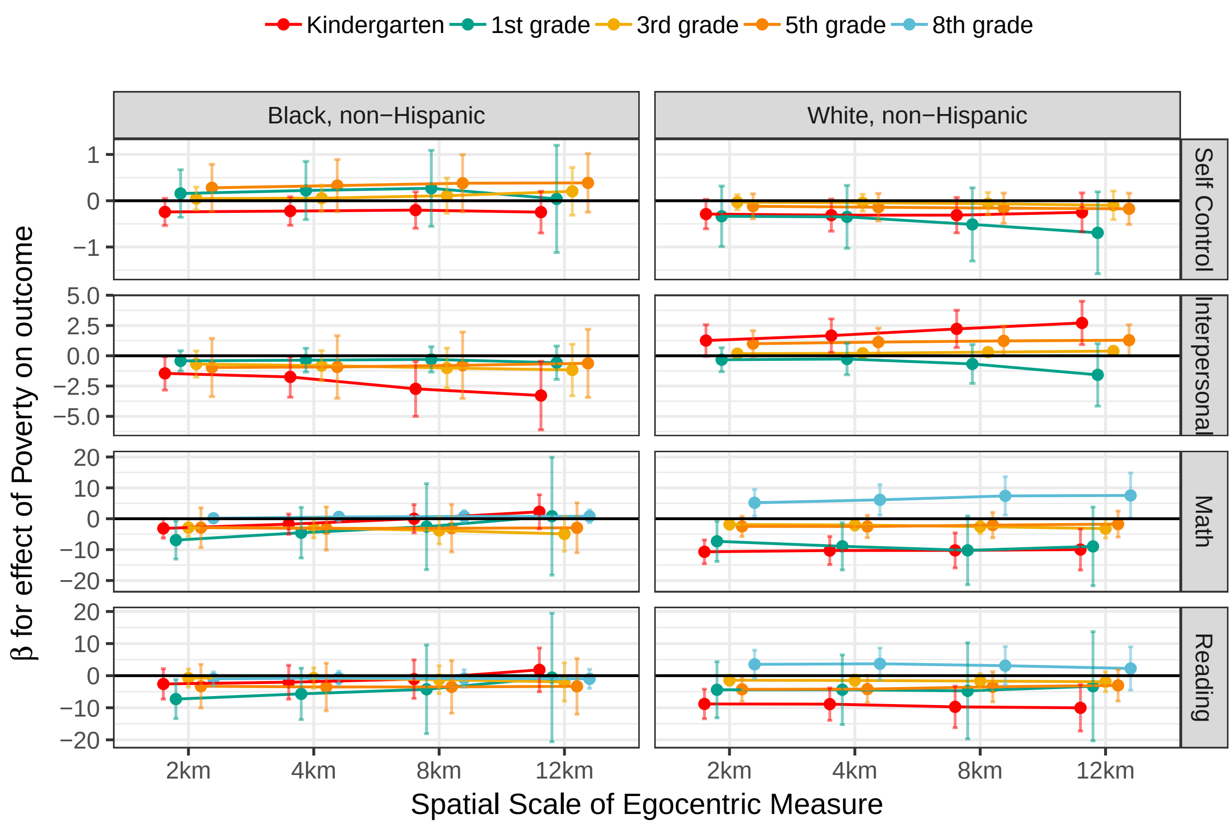

Figure 4: Model estimates of poverty-outcome association by spatial scale of residential poverty concentration

Does poverty-outcome association vary with the spatial granularity *of residential poverty?*

In addition to patterns of association by the egocentric spatial scale, we also examined the association between the *spatial granularity* of poverty using the log of the ratio of poverty at 12km to poverty measured at 2km kernel density bandwidths as the primary predictor of interest in regression models (see **Figure 5**). Recall that larger ratios reflect more extreme poverty at the broad, regional scale as compared to the local. In contrast, smaller ratios reflect local pockets of poverty that are more extreme than the broader region. For cognitive outcomes, larger granularity ratios in all grades except 3rd and 8th were associated with *higher* math and reading scores. There was little association between poverty granularity and non-cognitive outcomes, with the exception of interpersonal scale scores for Black children in 5th grade, where larger ratios were associated with *higher* scale scores.

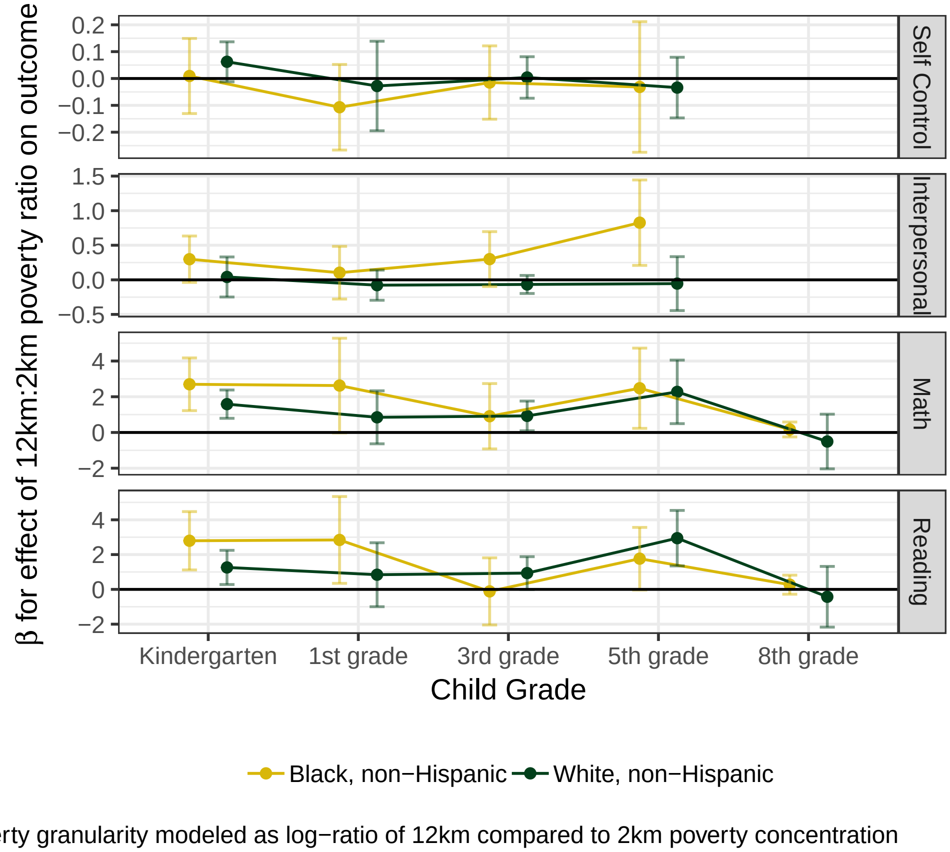

Figure 5: Model estimates of poverty-outcome association by poverty concentration granularity

Does poverty explain the Black-White racial disparity in outcomes?

Finally, we are interested in characterizing the degree to which observed racial disparities in child developmental outcomes are 'explained' by differences in experienced residential context, including poverty concentration. For this analysis, we first estimate the magnitude of the Black-White disparity or difference in each outcome (see **Figure 6, panel A**). We then re-fit each model, adjusting for residential environmental poverty concentration, and quantified the change in the racial disparity as a percent of the original gap (**Figure 6, panel B**).

Black children have lower average scores on both cognitive and non-cognitive outcomes, as compared with White children (*Panel A*). For math, reading, and self-control, the racial gap is largest in 3rd and 5th grade. For example, on average Black children scored 4-5 points lower on the reading scales in 3rd grade than did white children ($\beta = -4.3$, 95% CI: -5.1, -3.5). For math and reading in particular, adjustment for residential contextual poverty concentration attenuated the Black-White gap from 5-40%. This attenuation was primarily evident in kindergarten and first grade, and was strongest for poverty measured using the smallest spatial scale, 2km (*Panel B*).

A similar pattern of attenuation is evident for both non-cognitive measures for the kindergarten wave only, but relationships are more varied for subsequent ages.

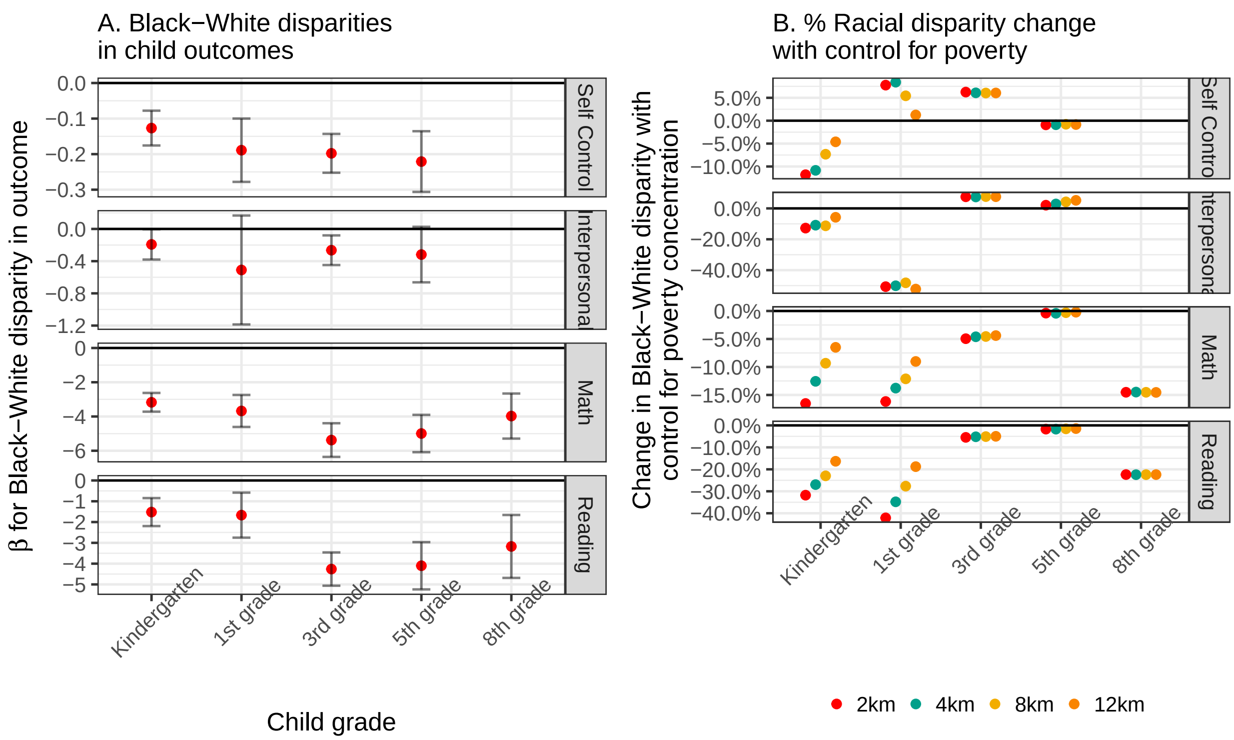

Figure 6: Black-White disparities in cognitive and non-cognitive outcomes

Discussion

Does neighborhood poverty concentration predict children's cognitive and non-cognitive skills and abilities as they age through elementary school and into adolescence? *Well, it depends.* The dynamics and drivers of children's developmental outcome are complex, arising from early life insults and resilience, family structure and dynamics, and socioeconomic status (Mollborn 2016, Heckman 2008). The meaning and nature of places are similarly complex, with population composition and change, built environment, and the broad geography of opportunity structures interacting in relational ways with residents and over time and across spatial scales (Lee et al. 2015, Cummins et al. 2007). It is therefore not surprising that there is no simple answer to the (oversimplified) question of whether neighborhood poverty does or does not predict child outcomes (Sharkey & Faber 2014). In this study we find that poverty concentration is associated with *some* children's cognitive (reading and math test scores), and non-cognitive (teacher assessed interpersonal skills and self-control) outcomes independent of family structure and socioeconomic status in *some age groups*, *some race groups*, and *some spatial scales*.

Residential environmental poverty concentration was most predictive of poorer cognitive and non-cognitive outcomes in children in kindergarten and first grade, and less so in 3rd, 5th, and 8th grades. This finding is consistent with the life course model of *critical and sensitive developmental periods* which posits that individual susceptibility to environmental insults or opportunities is most acute in particular developmental stages, including the pre-school years (Kane & Lam 2011, Ben-Shlomo et al. 2016, Phillips & Shonkoff 2000, Vaden-Kiernan et al. 2010). In contrast, our finding is not consistent with the hypothesis that neighborhood environment becomes more salient as children increase their independence and exposure to non-familial neighborhood environments. While there is evidence that neighborhood context does in some circumstances predict adolescent outcomes (Leventhal & Brooks-Gunn 2000), our findings are consistent with McFarland (2017) who found that poverty experienced during infancy and early childhood was predictive of later problem behaviors, but that poverty during adolescence was not independently predictive of outcomes. While these exploratory findings suggest the cross-sectional relationship between neighborhood poverty and child outcome is strongest in early elementary aged, children, important questions remain unanswered regarding within-child growth trajectories, the role of accumulated exposure to residential environmental poverty, and the possibly lagged effects of poverty on subsequent outcomes.

The question of how to define or operationalize neighborhoods often references concern about the modifiable areal unit problem (MAUP), which is a version of the ecologic fallacy in which possibly biased measures of association can result from the arbitrary zoning and spatial scale of aggregation of people into geographic units (Openshaw 1983). While the MAUP is a real concern for scholars of neighborhood effects, it is a limited perspective on the challenges and opportunities of spatial analysis. For instance, rather than fretting over selection of the 'optimal' definition of neighborhood (and therefore treating spatial scale and zoning problems as a nuisance inducing biased estimates), variations across nested scales and zones may be a 'feature', illuminating something distinct about the dynamic relations between populations and places (Lee et al. 2018, Chaix et al. 2005, 2017).

In the ECLS-K cohort, we observed relatively consistent *mean values* of poverty concentration in children's residential environment regardless of the spatial scale used. However, there was notably greater *between-place variation* in levels of poverty concentration when it was measured with 2km bandwidth spatial kernels as compared with 12km. Correspondingly the ratio of poverty concentration at 12km:2km quantified places where local and regional poverty were more or less concordant. On the one hand at some point larger bandwidth smoothing will inevitably produce greater homogeneity. However, the very existence of different spatial patterns – some characterized by widespread, regionally homogenous affluence or poverty, others characterized by small scale pockets of affluence and poverty – raises interesting questions about what aspects of places affect children and their families. For most outcomes and ages (and more so for Black as compared with White children), larger spatial *granularity ratios* were associated with *better* outcomes. Larger ratio values represent places where the micro environment is better of than the surrounding regional environment, and may reflect residual confounding by family socioeconomic status, or perhaps local differences in opportunities or cultural environment and child socialization (Caughy et al. 2006, 2007).

Limitations & Strengths

The size and scope of this nationally representative longitudinal cohort make it exceptionally well-suited for questions about child developmental trends and trajectories in the primary and middle school years. While cognitive measures were assessed via standardized tests with good psychometric properties, evaluating only reading and math scores is an incomplete evaluation of the range of children's cognitive abilities. Similarly, while the teacher-reported Social SKills Rating scale are a validated measure of non-cognitive skills and behaviors, there is potential that teacher bias with respect to race, class, or other factors, could influence their reporting and interpretation of behavior.

This study focused on the changing relationship between residential environmental poverty concentration and child outcomes across a 9-year span of early-middle child development. However, the current analytic strategy of cross-sectional age-specific associations is only a starting point at best. Further work evaluating within-child growth trajectories, and directly testing competing life course models including cumulative exposure scores are logical next steps.

Finally, our decision to focus on area-based poverty concentration and restriction to only non-Hispanic Black and White children was made in part because the exploratory questions were already highly dimensional. However, it is possible (likely?) that different patterns exist for other race and ethnic groups, and when measuring other indicators of place-based resources and opportunities. For example patterns of racial segregation correlate with but are not perfectly predicted by poverty concentration. Similarly, other contextual measures including social capital, social disorder, and access to specific resources (e.g. parks, walkable and connected spaces) are each examples of additional or alternative measures that theoretically affect the *proximal processes* of child development that may blunt or accelerate cognitive and non-cognitive skill acquisition.

Conclusion

Robust evidence points to the critically important role of early life development of cognitive and non-cognitive skills as likely causal predictors of adult social, economic, and health outcomes. Children's developmental outcomes are influenced by heritable traits and family dynamics and resources. But they may additionally be influenced by environmental opportunities and exposures beyond the family unit including aspects of the residential environment. In this study we examined whether one aspect of the neighborhood environment, poverty concentration, predicted cognitive and non-cognitive outcomes differently in space and time. Our finding that residential environmental poverty concentration may be more influential for younger as compared with older children, and that the spatial scale of measurement matters differently depending on the outcome, age, and race of the child highlights the complexity inherent in this social ecosystem.

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