The Role of Neighborhood Opportunity in Early Childhood Asthma and Differences by Urbanicity

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Abstract

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Introduction

Asthma is a prevalent chronic condition among children in the United States, with children in Washington state accounting for 20% of the state's estimated 600,000 asthma cases. Neighborhood environments during the sensitive developmental period of infancy can influence respiratory health, yet their role in the etiology of childhood asthma remains underexplored. The Childhood Opportunity Index (COI) offers a comprehensive measure of neighborhood-level structural, environmental, and socioeconomic factors. This study examined associations between COI scores during infancy with early childhood (4-6 years) asthma and wheeze, and whether these associations varied by urbanicity.

Methods

We analyzed data from 457 children enrolled in the ECHO PATHWAYS-GAPPS cohort across two Washington state sites: Seattle and Yakima. Neighborhood opportunity was assessed using COI scores categorized into very low/low, moderate, and high/very high opportunity; sensitivity

analyses used continuous scores scaled to the interquartile range (IQR). Asthma and wheeze outcomes were measured at the 4-6 year child visit via caregiver-reported validated questionnaires. Multivariable logistic regression estimated adjusted odds ratios (aORs) and 95% confidence intervals (CIs). Models were adjusted for child sex, maternal race/ethnicity, maternal education, maternal age at delivery, maternal history of asthma, study site, and household smoker. An interaction model tested for effect modification by urbanicity (recruitment site).

Results

Of the 457 participants, 207 caregivers were recruited from birthing centers at a hospital in Yakima and 250 from two Seattle hospitals. Most children (n=365; 79.9%) lived in neighborhoods classified as moderate and high/very high opportunity. Asthma and wheeze were reported in 11.5% and 12.6% of participants, respectively. No statistically significant associations were observed between overall COI and either outcome. Domain-specific analyses did not reveal strong associations, though estimates generally indicated increased odds of asthma and wheeze as neighborhood opportunity improved. No evidence of effect modification by urbanicity was found for asthma (p=0.519) and wheeze (p=0.802).

Conclusions

Neighborhood opportunity during infancy was not found to be associated with asthma or wheeze in early childhood (ages 4-6 years), and associations did not vary by urbanicity. Patterns of elevated odds in more opportune environments may reflect greater access to healthcare and caregiver engagement with diagnostic resources, rather than true differences in disease burden. Findings diverge from prior literature, highlighting the complexity of neighborhood influences on early respiratory health.

I. Introduction

Asthma remains one of the most prevalent chronic conditions among children, affecting 6.5% of those under 18 years old in the United States[1]. Washington state ranks among the states with the highest number of asthma cases, with children under the age of 18 making up 20% of the estimated 600,000 cases statewide[2]. Early childhood asthma contributes significant morbidity, including frequent hospitalization, poor sleep quality, and altered mood and mental states, all of which impact a child's overall growth and development[3-6]. The impacts of asthma are disproportionally experienced by socioeconomically disadvantaged populations, particularly Black, Indigenous, and People of Color [BIPOC] communities, highlighting the critical need to identify and address environmental and social determinants that contribute to these disparities[7,8].

Neighborhood characteristics, such as social, economic, cultural, and built features are integral in shaping early childhood health outcomes[8,9]. Neighborhood opportunity measured by the Childhood Opportunity Index (COI) provides a robust framework to quantify factors of neighborhood opportunity, such as educational resources, access to healthcare, environmental quality, and socioeconomic conditions, providing insight into the social contexts that influence health[10]. Prior research has linked lower COI scores to adverse health outcomes across childhood, including developmental delays and increased asthma hospitalization [4,11-17]. Emerging evidence suggests that early-life social exposures, such as access to healthy food, walkability, and neighborhood-level socioeconomic disadvantage at birth or in early life have also been associated with adverse health outcomes, such as growth, obesity, and cardiovascular conditions throughout childhood and into adulthood[9, 11, 18].

Infancy may represent a particularly sensitive and formative development window, during which neighborhood conditions exert influence on respiratory outcomes. During this stage, infants primarily experience their environment through caregiver-mediated interactions, but neighborhood conditions during this early life stage can significantly influence respiratory health through several mechanisms. For example, poor housing conditions common in disadvantaged neighborhoods can increase exposure to indoor air pollutants, mold, or pests, which are factors infants are particularly vulnerable to due to their developing immune and respiratory systems[19]. Moreover, infants spend most of their time indoors or close to home, tightly linking exposures to their immediate surroundings[20]. Neighborhood disadvantage can also elevate caregiver stress and reduce the capacity to provide protective and enriching environments[21]. Collectively, these social and environmental mechanisms illustrate how investigating neighborhood contexts during critical exposure periods, like infancy, can help understand the early and cumulative effects on respiratory health in early childhood[8]. The COI 2.0, while not capturing all these factors, serves as a useful proxy for the environmental conditions that shape early-life exposure.

Neighborhood characteristics across urbanicity (urban to rural) gradients present unique constellations of factors that influence childhood asthma. Urban environments are often associated with risk factors such as traffic-related air pollution, industrial emissions, and overcrowding[14, 22,23]. In contrast, while rural areas are typically less dense, asthma prevalence remains comparable to those urban areas, likely due to different but equally important risk

factors such as limited access to healthcare, economic disparities, and poor housing quality, and environmental exposures like agricultural dust and pesticides [24-26]. These patterns emphasize the importance of considering both broad urban-rural classifications and finer-scale neighborhood variation when examining early childhood asthma or wheeze outcomes.

Understanding how neighborhood opportunity during infancy impacts early childhood asthma, particularly across different urbanicity contexts, may inform approaches to address asthma disparities. While previous studies have examined the link between COI during later childhood and asthma outcomes, exacerbations, and hospitalizations during childhood,[24,26,3,12] the role of neighborhood opportunity during infancy and its interaction with urbanicity in shaping childhood asthma remains largely unexplored. Although childhood asthma is not reliably diagnosed until early school age[27], it is widely recognized that early-life factors, including prenatal and infancy exposures, play a critical role in shaping respiratory health and asthma risk[28]. By addressing these gaps, this research will provide a more comprehensive understanding of how early-life neighborhood factors contribute to asthma outcomes in children.

We evaluated the association between neighborhood opportunity during infancy, as measured by the Child Opportunity Index (COI) scores, and the odds of early childhood asthma and wheeze in a well-characterized longitudinal cohort that included participants in a large urban metropolitan area (Seattle) and a town situated in a rural county with rural characteristics (Yakima). We hypothesized that lower neighborhood opportunity during infancy would be associated with higher odds of asthma and wheeze in children ages 4-6 years. As a secondary aim, we investigated the association between individual COI domains (Education, Health and Environment, and Social and Economic opportunity) and asthma and wheeze outcomes. Finally, we assessed whether associations between neighborhood opportunity during infancy and early childhood asthma and wheeze differed by participant residence, hypothesizing that the adverse association would be stronger among children residing in Yakima compared to the Seattle based families. By addressing these gaps, our research contributes to understanding how neighborhood contexts influence early childhood asthma and guide efforts to reduce asthma disparities across diverse settings.

II. Methods

Study Population

This study includes mother-child dyad participants from the Global Alliance to Prevent Prematurity and Stillbirth [GAPPS] prospective cohort. The GAPPS study was a part of the ECHO PATHWAYS cohort, a research center funded by the national NIH Environmental influences on Child Outcomes [ECHO] Program[29]. Participants ages 18 years or older and English speaking were initially enrolled during the first trimester of pregnancy as a part of a closed biorepository cohort. In Seattle, participants receiving prenatal care in either the Swedish Medical Center or the University of Washington Medical Center were recruited. While in Yakima, participants were recruited from the Yakima Valley Memorial Hospital. Those who

consented for future contact, had children who met the eligibility criteria based on age, and had available prenatal data were subsequently re-contacted and invited to enroll themselves and their child into the ECHO PATHWAYS cohort.

The first visit for child participants occurred during early childhood (ages 4–6-years), where mothers completed self-administered surveys, including the International Study of Asthma and Allergies in Childhood [ISAAC] questionnaire[30] to assess their child's respiratory health. These surveys also collected information on parental asthma history and smoking status, residential address history from pregnancy through early childhood, as well as other health and lifestyle factors [26].

A total of 673 children were assessed for eligibility for this secondary data analysis based on their completion of the 4-6 year child visit. Eligibility criteria included completion of the 4-6 year early childhood visit, including having provided responses to the ISAAC survey, and availability of the residential address history during infancy. Children younger than 4 years of age or older than 7 years were excluded from the analysis.

All ECHO PATHWAYS-GAPPS research activities were approved by the University of Washington Institutional Review Board (IRB, Study ID: STUDY00000638).

Child Opportunity Index (Study Exposure Metric)

The primary exposure of interest was neighborhood opportunity during infancy, measured using the 2010 Childhood opportunity Index (COI) version 2.0, developed by Diversitydatakids.org. The COI was originally created to identify and map the inequitable distribution of neighborhood resources that are critical for healthy child development, and to inform policies aimed at reducing disparities that exists between neighborhood opportunity and children's health. This index is a composite measure that uses census-tract level data to quantitatively capture the social, built, and structural environmental conditions of the neighborhood. These conditions are measured across 29 indicators under three domains: Education, Health and the Environment, and Social and Economic domains. Domain-specific data are derived from multiple sources, including the U.S Census Bureau, Environmental Protection Agency, and National Center for Education Statistics[10].

Residential address data reported by child caregivers for the child's first year of life (birth-1 year) were geocoded and linked to census tract-level COI scores, including a total COI score and three domain scores. For participants who reported multiple addresses during the infancy period, the COI scores incorporated a weighted average of census tract-level scores corresponding to each residential address provided. The COI scoring structure for this study is hierarchical; it includes 29 subdomain indicators, each standardized as a z-score. Domain scores were then calculated as the average of their respective subdomain z-scores, and the overall COI score was then computed as the average of those domain scores.

To facilitate interpretation of results, the continuous overall COI score was categorized into a three-category variable that collapses the original five categories of opportunities defined by Diveristydatakids.org. These three levels include: Very low/Low, Moderate, and High/Very high. This binning approach also helped account for the limited sample sizes within the original five categories. To assess the robustness of results using the categorical exposure variable, a sensitivity analysis was conducted using the continuous overall COI score.

To further investigate which neighborhood conditions may be most influential, each of the three domain-specific (Education, Health and the Environment, and Social and Economic) COI scores was also evaluated individually. These domain-specific scores were similarly categorized into a three-level variable and assessed in relation to asthma and wheeze outcomes. Sensitivity analyses used individual domain continuous scores in separate models.

Study Locations (Potential Effect Modifier)

Effect modification by urbanicity was assessed by study site as a proxy, with participants classified as either urban (Seattle) or rural-like (Yakima) neighborhoods based on their recruitment residence. Although Yakima town is not rural by population density, it is nested within a predominantly rural and agricultural county. Yakima county ranks among the highest agricultural producers in Washington state, with surrounding areas characterized by extensive orchards, vineyards, and crop fields[31,32]. These geographic and economic features contribute to a regional context more closely aligned with rural rather than urban environments. In addition, the town of Yakima also demonstrates socioeconomic, structural, and built environment characteristics typical of rural communities. These include lower socioeconomic indicators (educational attainment and high poverty rates), limited access to healthcare facilities, and long travel times to specialized medical services[33-35]. Taken together, these characteristics supported the classification of Yakima as a "rural-like" setting for the purposes of this study.

Asthma and Wheeze Outcomes

The two primary outcomes of interest in this study, asthma and wheeze, were treated as binary variables (yes/no) and were assessed based on caregiver responses at the age 4-6 visit to the ISAAC questionnaire[30]. Due to the challenges of diagnosing asthma in early childhood, wheezing, a common asthma-related characteristic, was also included as a primary outcome[29].

Asthma was defined as a positive response to at least two out of three following ISAAC questions: (1) "Has your child ever had asthma?"; (2) "Has your child ever had wheezing or whistling in the chest in the last 12 months?"; (3) "In the past 12 months has your child used any type of medicines, liquids, puffers or other medication for wheezing or asthma?"

Wheeze was defined as a positive response to the question, "Has your child ever had wheezing or whistling in the chest in the last 12 months?"

Covariates

Confounders and precision variables were selected *a priori* based on established literature on early childhood asthma outcomes and construction of a DAG (Figure 1). Variables included child and maternal, and study-level characteristics.

Child factors include child age at outcome assessment (continuous) and sex as well as child's postnatal household exposure to smoking (yes/no).

Maternal factors included maternal education at pregnancy categorized as high school or less, vocational or technical school or associate's degree, college degree, and graduate or professional degree. Maternal race and ethnicity were included as a proxy for exposure to historic factors and experiences linked to health outcomes (non-Hispanic White, Hispanic White, multiple races, or underrepresented/unspecified racial/ethnic identity). Further breakdown of racial categories was not possible due to limited representation in smaller subgroups. Maternal history of asthma (yes/no) was also included as a precision variable[36]. Maternal education, race/ethnicity, and age at delivery (continuous, centered) were considered as potential confounders due to their association with both neighborhood opportunities and child health outcomes.

Study-level factors included recruitment site, categorized as Seattle (two Seattle locations were collapsed) or Yakima, and was included as a confounder for the primary analysis models to account for potentially unmeasured or residual social, structural, and geographical differences in neighborhoods opportunity and asthma and wheeze outcomes.

Statistical Analysis

Descriptive statistics were used to explore the characteristics of the study populations as a whole and by study site. Frequencies, means, and standard deviations were computed for categorical and continuous variables, respectively.

Participants missing data on the exposure variable were excluded. Individuals with available date for either or both asthma or wheeze outcomes were retained for the analysis (Fig. 1).

For the primary analysis, multivariable logistic regression with robust standard errors was conducted to estimate odd ratios (ORs) and 95% confidence intervals to measure the association between the association between overall neighborhood opportunity with asthma (current asthma or current wheeze). COI overall scores were modeled categorically to compare asthma and wheeze odds across levels of opportunity (Very low/Low, Moderate, and High/Very high).

A sensitivity analysis was performed by rerunning the logistic regression modelling the exposure as a continuous variable to assess the robustness of the primary findings. Odds ratios were scaled to an IQR increase in overall COI score.

For domain-specific analyses, multivariable logistic regression models were run for each of the three domain-specific scores as a categorical variable (Very low/Low, Moderate, and High/Very high). Sensitivity analysis for domain-specific COI was also conducted by using each domain's continuous score scaled to its respective IQR. This statistical approach allowed for more granular understanding of how each domain of opportunity affected early childhood asthma and wheeze outcomes.
Effect Modification by urbanicity (Seattle and Yakima) was explored by including an interaction term between the overall conitnous COI score and study site. Two models were fit for each outcome: one using Seattle as a reference category and one using Yakima. Interaction models were used to estimate an interaction p-value, as well as site-specific associations.

All models adjusted for confounders and precision variables, as outlined in the covariate section. Statistical significance was set at a p-value of α=0.05, and all analysis was preformed using R 4.5.0 (R Foundation for Statistical Computing, Vienna, Austria).

III. Results

Of the 637 PATHWAYS-GAPPS participants who completed the 4- 6 year early childhood visit, 519 had caregiver-reported residential address histories available for calculating COI scores. Among these, 457 had data on asthma and/or wheeze and were included as the analytical sample (Figure 2).

Within this sample, 207 caregivers were recruited in Yakima, while the remaining 250 were recruited from the two sites in Seattle. The distribution of child sex at birth was 47.9% female and 52.1% male. Mean child age during the 4-6 year early childhood visit was 6.0 (SD=1). Reported maternal race and ethnicity were predominantly Non-Hispanic White (74.6%). Average annual household income at enrollment was $56,530 if recruited in Yakima and $73, 911 if recruited from Seattle. Maternal education levels were relatively high with over 88.1% reporting at least an associate's degree and above. Additionally, 14.7% of mothers reported a history of asthma and only 7.5% (34) reported having a household smoker after the child's birth (Table 1).

Within the cohort, 9.8% of caregivers in Yakima and 12.8% in Seattle reported their child as having current asthma. Reports of current wheeze were 14.1% in Yakima and 10.6% in the Seattle group (Table 2). Additionally, the distributions of participants across neighborhood opportunity was skewed, with over half (56.9%) living in high/very high opportunity neighborhoods overall, including 69.2% of those residing in Seattle and 42.0% in Yakima. Notably, there were stark differences in educational opportunity, with 57.0% of Yakima participants living in low/very low educational opportunity neighborhoods compared to only 16.8% in Seattle (Table 3).

Infancy COI and Asthma

When compared to children living in neighborhoods with very low/low opportunity, children living in neighborhoods with moderate and high/very high overall COI scores during infancy had higher odds of asthma at ages 4-6 years (aOR: 1.66; 95% CI: 0.54, 5.14 and aOR: 1.78; 95% CI: 0.61, 5.19, respectively). Results were similar in sensitivity analysis using the continuous overall COI score, where each IQR increase in overall COI corresponded to 1.30 times the higher odds of asthma (95% CI: 0.81, 2.11).

Domain-specific analysis largely followed a similar pattern. For the education domain, high/very high neighborhood education opportunity had higher odds (aOR: 1.34; 95% CI: 0.50, 3.48) of developing asthma, compared to the very low/low opportunity areas. This trend was also observed in the sensitivity analysis with an odds ratio of 1.22 (95% CI: 0.67, 2.19). Similarly, higher level of social and economic opportunity were associated increased odds of asthma across both categorical and continuous models.

Findings from the Health and Environmental COI domain were more inconsistent and imprecise. While moderate and high/very high neighborhood opportunity appeared slightly protective in the categorical analysis, these results were inconsistent with the continuous model (aOR: 1.18; 95% CI: 0.77, 1.80), which also suggested a similar trend of higher odds of asthma as neighborhood opportunity increased (Table 4).

Wheeze

In the primary model, compared to children living in very low/low opportunity neighborhoods, those living in moderated neighborhoods in infancy had similar odds of reporting wheeze (aOR: 1.09; 95% CI: 0.35, 3.40). While those in high/very high opportunity neighborhood had higher odds (aOR: 2.13; 95% CI: 0.80, 5.69), though both levels were not statistically significant. In sensitivity analysis using the continuous COI score, each IQR increase in overall COI showed elevated but non-significant odds of wheeze (aOR: 1.51; 95% CI: 0.94, 2.43).

Domain-specific results were generally consistent with overall patterns. For the education domain, odds of wheeze were mildly elevated scross both categorical and continuous models, though non were statistically significant. The health and environment domain, odds of wheeze were lower in moderate (aOR: 0.34; 95% CI: 0.06, 1.92) and high/very high (aOR: 0.73; 95% CI: 0.21, 2.51) neighborhoods compared to the reference group; however, this was not reflected in the sensitivity analysis (aOR: 1.12; 95% CI: 0.75, 1.69).

In contrast, higher social and economic opportunity during infancy was observed to have greater odds of wheeze. Compared to the very low/low group, odds were significantly higher in the moderate (aOR: 3.10; 95% CI: 1.09, 8.83) and high/very high (aOR: 3.19; 95% CI: 1.21, 8.42) neighborhoods. This trend was supported in the sensitivity analysis, though confidence intervals were wide and included the null (aOR: 1.59; 95% CI: 0.99, 2.54) (Table 5).

Effect Modification

Interaction models were fit to explore urbanicity as potential modifier using the continuous overall COI score. Results for asthma yielded no evidence of effect modification by urbanicity (p=0.519). Site specific effect estimates in the association between overall COI and asthma remained null and not statistically significant in the Seattle sample (aOR: 1.07; 95% CI: 0.48, 2.37) and Yakima participants (aOR: 1.44; 95% CI: 0.85, 2.44). Similarly, for wheeze outcomes, the interaction term did not support effect modification (p = 0.802) and effects of COI were comparable in Seattle (aOR: 1.41; 95% CI: 0.67, 2.97) and Yakima (aOR: 1.58; 95% CI: 0.91, 2.76) specific analyses (Table 6).

IV. Discussion

This study aimed to examine whether neighborhood opportunity during infancy, a critical period for respiratory development, was associated with the odds of asthma and wheeze in early childhood, and whether these associations differed by urbanicity. Using data from a longitudinal cohort of children residing in urban and rural-like settings in Washington state, we hypothesized that lower neighborhood opportunity would be associated with higher odds of asthma and wheeze, particularly among children living in more rural contexts. Contrary to this hypothesis, we found no consistent associations between neighborhood opportunity in infancy and early childhood asthma or wheeze, nor evidence that urbanicity modified these relationships.

Several studies examining neighborhood opportunity, as measured by the COI, and childhood asthma have found that higher COI scores are associated with lower asthma risk. A large, multi-site cohort study reported that children born into high and very high opportunity neighborhoods had a reduced risk of asthma diagnoses compared to those in very low opportunity areas, with strongest associations with the health and environment and social and economic domains and no associations observed with the education domain[16]. Similarly, the ECHO/CREW study found that children born into neighborhoods with higher poverty, population density, and lower individual income, had elevated risks for early wheeze, persistent wheeze (a precursor to asthma), and asthma incidence by age 11[15]. Research examining change in neighborhood opportunity over time has also shown that a downward mobility in opportunity during the first three years of life is associated with increased odds of physician-diagnosed childhood asthma, though not with recurrent wheeze[17].

Differences in exposure timing, outcome assessment, and geographic scope may account for the discrepancies and variation in observed associations in past literature and those of our study. Unlike prior research that assessed neighborhood opportunity at multiple timepoints from birth and throughout childhood, this analysis focused exclusively on conditions during infancy as sensitive developmental window. Additionally, previous studies evaluated asthma outcomes across a broader age range, including middle childhood and early adolescence, while our study

restricted outcome assessment at ages 4-6 years, which may have excluded cases with later onset and contributed to difference in observed odds. Much of the existing literature also draws from national datasets or large urban-based cohorts, whereas our study used a Washington state-based sample that included both a major metropolitan area and a rural county.

The direction of associations observed in our analysis diverged from hypothesized expectations. Contrary to prior research suggesting protective effects with higher neighborhood opportunity, we observed somewhat higher odds of asthma and wheeze among children living in moderate and high/very high opportunity neighborhoods across both overall and domain-specific models. While a general trend of increasing odds with higher opportunity was noted, these results were highly imprecise, with confidence intervals included the null. One possible explanation is differential access to healthcare across neighborhoods. Children residing in high opportunity areas benefit from neighborhood-level access to healthcare and diagnostic services, including more frequent pediatric visits and screenings, increasing the likelihood of asthma and/or wheeze being identified and reported by caregivers[37]. In contrast, lower opportunity neighborhoods may be characterized by limited healthcare access, contributing to underdiagnosis and delayed recognition of respiratory of symptoms[34]. The health and environment domain, which includes an indicator for health insurance coverage, captures some of this contextual variation. Notably, some estimates for this domain were in the hypothesized protective direction, albeit null, lending partial support to the idea that neighborhood-level health care access may influence patterns of reported asthma and wheeze. Additionally, our sample was skewed toward high maternal socioeconomic status with 88.1% of caregivers reporting at least an associate's degree. While maternal education was adjusted for in our models, limited variability in socioeconomic indicators may have reduced our ability to detect true associations with neighborhood opportunity. It is also worth noting that the presence of our outcome, asthma (11.4%) and wheeze (12.2%), in our sample was not considered rare and may have led to odds ratios that overestimate the risk.

Urbanicity was not found to modify the relationship between neighborhood opportunity and asthma and wheeze outcomes in this study. An explanation for this is that the COI already accounts for several key factors, such as healthcare access, air quality, and SES inequalities, which typically vary by urbanicity[10]. As a result, the COI may have accounted much of the variability that would otherwise be attributed to differences between urban and rural settings.

While these results do not support definitive conclusions about association, the consistency in direction across models may reflect meaningful patterns in how neighborhood opportunity relates to respiratory outcomes and warrant further investigation. To further explore the relationship between neighborhood opportunity and asthma outcomes, future research could build on this work by employing a multilevel approach that accounts for both individual and neighborhood-level factors beyond those captured by the COI. A mixed effects modelling

framework would allow for variation across neighborhoods and account for clustering effects offering a more nuanced understanding of contextual conditions impacting early childhood asthma and wheeze outcomes. Moreover, future studies could further explore the role of urbanicity in early childhood asthma by employing more granular measures of urbanicity such as distinctions between city centers, suburban, and rural regions to better capture the heterogeneity in environmental and social exposures across geographic settings. These approaches could provide insight into the unique mechanisms that influence asthma and wheeze disparities within these areas and inform targeted public health interventions.

Strengths

This study contributes to an underexplored area by examining neighborhood opportunity during infancy and its relationship to early childhood asthma and wheeze. By leveraging data from two distinct settings in Washington state, this study uniquely examines potential differences across urban and rural-like environments using consistent study protocols, allowing for comparison between sites within a shared framework. The inclusion of residential address history within the first year of life strengthens the exposure assessment, as few prior studies have focused specifically on neighborhood conditions during infancy. The use of a validated composite measure (COI 2.0) allowed for a multidimensional assessment of opportunity across domains relevant to child development and respiratory. Additionally, the availability of key covariates at both the maternal and child levels enabled adjustment for important potential confounders, and outcomes were assessed using a standardized and well-established instrument. Together, these study features provide a solid foundation for investigating how neighborhood conditions in early life may relate to early signs of asthma risk.

Limitations

This study has several limitations. First, the relatively small number of asthma and wheeze cases limited the statistical power to detect modest associations and contributed to imprecise estimates, as reflected in wide confidence intervals. While sensitivity analyses provided slightly narrower estimates, results remained imprecise and largely non-significant. Second, our study had a substantial amount of missing data on residential history which may introduce selection bias. Participants who did not report residential addresses may be experiencing greater housing instability and be more likely to live in neighborhoods with lower COI scores, potentially leading to an underestimation of the associations explored. Third, the generalizability of results is limited, as the sample is drawn from participants residing in Seattle and Yakima, Washington, which may not reflect other regions with different socioeconomic, demographic, and environmental conditions. This includes our Yakima sample which is predominantly non-Hispanic White and of higher socioeconomic status compared to the overall Yakima County. Consequently, this indicates a low representation of the more vulnerable families in the Yakima valley, limiting our ability to capture the full range of environmental and social exposures experienced in this region. Fourth, because GAPPS only recruited English-speaker, the ISAAC

survey was only administered exclusively in English, which likely excluded a substantial portion of the Spanish-speaking community in Yakima.

Additionally, the COI was measured as a static exposure at infancy and does not account neighborhood changes or residential mobility after the first year of life. As a result, the exposure may not reflect the cumulative or shifting environmental influences. Asthma and wheeze outcomes were caregiver-reported and may be subject to measurement error, particularly if diagnosis and symptom recognition vary by opportunity level. Finally, outcomes were modeled as binary indicators, which do not capture severity, exacerbations, or hospitalization frequency. This may have limited the ability to detect more nuances in the relationship between neighborhood opportunity and asthma and wheeze outcomes.

V. Conclusions

In conclusion, this study did not identify significant associations between neighborhood opportunity during infancy, as measured by the COI 2.0, and asthma or wheeze outcomes in early childhood. Although the primary analyses yielded null results, consistent trends of higher effect estimates with higher COI scores across overall and domain-specific models, suggest patterns that warrant further attention. These findings contribute to a limited but growing body of research focused on early-life neighborhood factors influences on respiratory health, highlighting the complexity of these relationships and the importance of continued exploration in this area.

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Tables and Figures

Figure 1: DAG

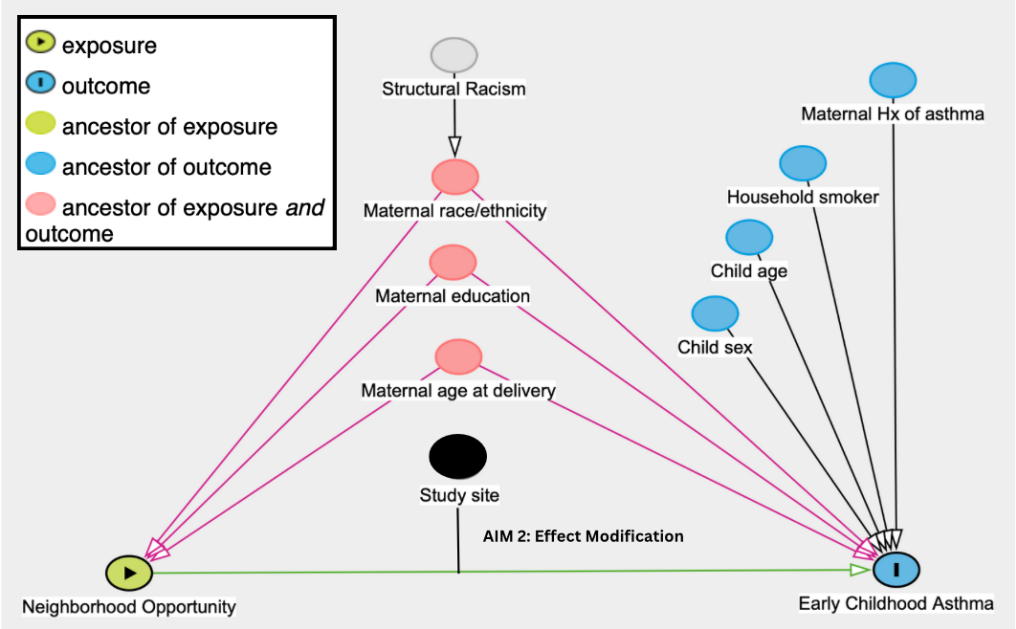

Figure 2: Analytic Sample Flow Chart

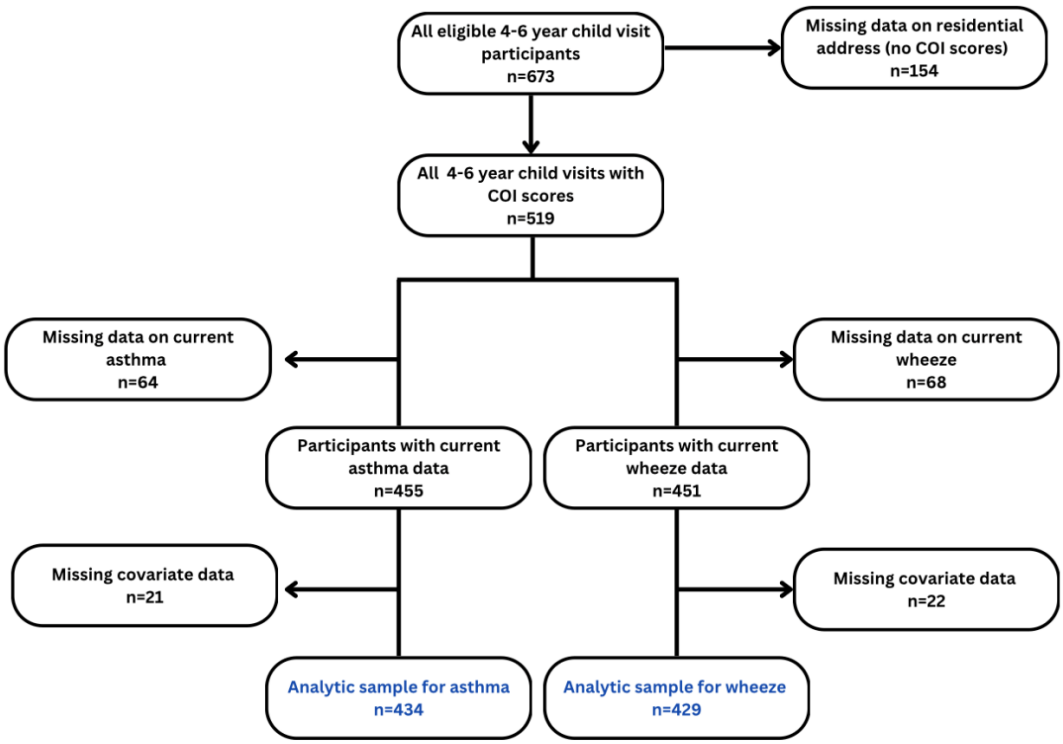

Table 1: ECHO PATHWAYS-GAPPS Cohort Characteristics (2010-2017)

Variable	Overall (n = 457)[1]	Study Site	
		Yakima N = 207	Seattle N = 250
Child sex at birth (n (%))			
F	219 (47.9%)	103 (49.8%)	116 (46.4%)
M	238 (52.1%)	104 (50.2%)	134 (53.6%)
Child's age at early childhood visit (Mean (SD))	6 (1)	6 (1)	5 (1)
Maternal race/ethnicity (n (%))			
Non-Hispanic White	341 (74.6%)	154 (74.4%)	187 (74.8%)
Hispanic White	27 (5.9%)	21 (10.1%)	6 (2.4%)
Multiple races	25 (5.5%)	9 (4.3%)	16 (6.4%)
Underrepresented or unspecified race/ethnicity	64 (14.0%)	23 (11.1%)	41 (16.4%)
Household income (Mean (SD))	66,007 (25,607)	56,530 (25,873)	73,911 (22,563)
Missing	15	6	9
Maternal level of education (n (%))			
High school or less	54 (11.9%)	34 (16.7%)	20 (8.0%)
Vocational or technical school, or Associate's degree	100 (22.1%)	64 (31.4%)	36 (14.5%)
College degree	160 (35.3%)	62 (30.4%)	98 (39.4%)
Graduate or professional degree	139 (30.7%)	44 (21.6%)	95 (38.2%)
Missing	4	3	1
Maternal age at delivery (Mean (SD))	32 (5)	30 (5)	34 (5)
Maternal history of asthma (n (%))			
no	390 (85.3%)	172 (83.1%)	218 (87.2%)
yes	67 (14.7%)	35 (16.9%)	32 (12.8%)
Household smoker (postnatal) (n (%))			
no	419 (92.5%)	184 (89.8%)	235 (94.8%)
yes	34 (7.5%)	21 (10.2%)	13 (5.2%)
Missing	4	2	2

[1] Overall sample includes participants with either or both asthma and wheeze outcome data

Table 2: Asthma and Wheeze Outcomes by Study Site

Outcome	Overall N = 457[1]	Study Site: Yakima N = 207[1]	Study Site: Seattle N = 250[1]
Asthma			
no	403 (88.6%)	185 (90.2%)	218 (87.2%)
yes	52 (11.4%)	20 (9.8%)	32 (12.8%)
Missing	2	2	0
Wheeze			
no	396 (87.8%)	176 (85.9%)	220 (89.4%)
yes	55 (12.2%)	29 (14.1%)	26 (10.6%)
Missing	6	2	4

[1] n (%)

Table 3: Distribution of Childhood Opportunity Index Scores (Overall and by Domain) by Study Site

Exposure	Overall (n = 457)[1]	Study Site: Yakima N = 207	Study Site: Seattle N = 250
Overall COI (categorical) (n(%))			
Very Low/ Low	92 (20.1%)	58 (28.0%)	34 (13.6%)
Moderate	105 (23.0%)	62 (30.0%)	43 (17.2%)
High/Very High	260 (56.9%)	87 (42.0%)	173 (69.2%)
Overall COI (averaged score) (Mean (SD))	0.01 (0.02)	0.00 (0.02)	0.02 (0.02)
COI-Education Domain (categorical) (n(%))			
Very Low/ Low	160 (35.0%)	118 (57.0%)	42 (16.8%)
Moderate	119 (26.0%)	82 (39.6%)	37 (14.8%)
High/Very High	178 (38.9%)	7 (3.4%)	171 (68.4%)
COI-Education Domain (averaged score) (Mean (SD))	0.01 (0.07)	-0.04 (0.04)	0.04 (0.06)
COI-Health and Environment Domain (categorical) (n(%))			
Very Low/ Low	20 (4.4%)	9 (4.3%)	11 (4.4%)
Moderate	39 (8.5%)	19 (9.2%)	20 (8.0%)
High/Very High	398 (87.1%)	179 (86.5%)	219 (87.6%)
COI-Health and Environment Domain (averaged score) (Mean (SD))	0.06 (0.02)	0.06 (0.02)	0.06 (0.02)
COI-Social and Economic Domain (categorical) (n(%))			
Very Low/ Low	119 (26.0%)	67 (32.4%)	52 (20.8%)
Moderate	97 (21.2%)	50 (24.2%)	47 (18.8%)
High/Very High	241 (52.7%)	90 (43.5%)	151 (60.4%)
COI-Social and Economic Domain (averaged score) (Mean (SD))	0.06 (0.15)	0.02 (0.14)	0.10 (0.15)

[1] Overall sample includes participants with residential address history during infancy and with either or both asthma and wheeze outcome data

Table 4: Logistic Regression Results for Neighborhood Opportunity and Asthma

Asthma Logistic Regression Results for Neighborhood Opportunity and Asthma		
	aOR[1]	95% CIs
Overall COI		
Very low/Low	Ref.	Ref.
Moderate	1.66	(0.54, 5.14)
High/Very high	1.78	(0.61, 5.19)
Continuous (per IQR increase)	1.30	(0.81, 2.11)
COI - Education		
Very low/Low	Ref.	Ref.
Moderate	0.75	(0.28, 1.97)
High/Very high	1.34	(0.50, 3.58)
Continuous (per IQR increase)	1.22	(0.67, 2.19)
COI - Health and Environment		
Very low/Low	Ref.	Ref.
Moderate	0.06*	(0.00, 0.87)
High/Very high	0.68	(0.15, 2.99)
Continuous (per IQR increase)	1.18	(0.77, 1.80)
COI - Social and Economic		
Very low/Low	Ref.	Ref.
Moderate	2.29	(0.85, 6.18)
High/Very high	1.71	(0.67, 4.35)
Continuous (per IQR increase)	1.31	(0.82, 2.11)

[1] All models adjusted for child sex, child age, maternal race/ethnicity, maternal education, maternal age at delivery, maternal history of asthma, study site, and household smoker. Asterisk (*) indicates $p < 0.05$.

Table 5: Logistic Regression Results for Neighborhood Opportunity and Wheeze

Wheeze Logistic Regression Results for Neighborhood Opportunity and Wheeze		
	aOR[1]	95% CIs
Overall COI		
Very low/Low	Ref.	Ref.
Moderate	1.09	(0.35, 3.40)
High/Very high	2.13	(0.80, 5.69)
Continuous (per IQR increase)	1.51	(0.94, 2.43)
COI - Education		
Very low/Low	Ref.	Ref.
Moderate	1.12	(0.46, 2.70)
High/Very high	1.85	(0.73, 4.70)
Continuous (per IQR increase)	1.29	(0.72, 2.30)
COI - Health and Environment		
Very low/Low	Ref.	Ref.
Moderate	0.34	(0.06, 1.92)
High/Very high	0.73	(0.21, 2.51)
Continuous (per IQR increase)	1.12	(0.75, 1.69)
COI - Social and Economic		
Very low/Low	Ref.	Ref.
Moderate	3.10*	(1.09, 8.83)
High/Very high	3.19*	(1.21, 8.42)
Continuous (per IQR increase)	1.59	(0.99, 2.54)

[1] All models adjusted for child sex, child age, maternal race/ethnicity, maternal education, maternal age at delivery, maternal history of asthma, study site, and household smoker. Asterisk (*) indicates $p < 0.05$.

Table 6: Site Specific Association Between Overall COI and Asthma and Wheeze

Site-Specific Association Between Overall COI and Asthma and Wheeze Effect Modification (Continuous COI per IQR increase)				
	Asthma (Interaction p = 0.519)		Wheeze (Interaction p = 0.802)	
	aOR[1]	95% CIs	aOR	95% CIs
Yakima	1.44	(0.85, 2.44)	1.58	(0.91, 2.76)
Seattle	1.07	(0.48, 2.37)	1.41	(0.67, 2.97)

[1] Adjusted for child sex, child age, maternal race/ethnicity, maternal education, maternal age at delivery, maternal history of asthma, and household smoker.