Associations among Neighborhood, Race, and Sleep Apnea Severity in Children

A Six-City Analysis

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Abstract

Rationale: Prior researchers found that individual-level environmental and social indicators did not explain the racial disparity in obstructive sleep apnea syndrome. Neighborhood socioeconomic variables, as well as risk factors for a range of adverse behavioral and health outcomes, may better explain this racial disparity and help identify modifiable intervention targets.

Objectives: To evaluate the associations of neighborhood socioeconomic variables with obstructive sleep apnea severity and to assess whether the neighborhood variables explain the association between race and obstructive sleep apnea severity.

Methods: We performed a cross-sectional analysis of data of 774 children in six cities who participated in the Childhood Adenotonsillectomy Trial. The outcome variable was the apnea–hypopnea index (AHI). Neighborhood socioeconomic variables were obtained on the basis of the children's residential addresses and information in the American Community Survey. Regression models were used to assess the associations among neighborhood conditions, race, and AHI.

Measurements and Main Results: Higher poverty rate and percentage of single-female–headed households were associated with higher AHI ($P = 0.008$ and 0.002, respectively). African American race was associated with a 1.33 (1.08–1.64 95% confidence interval)-fold increase in AHI, adjusting for age and sex. After controlling for poverty rate or percentage of single-female–headed households with children, the association between race and AHI levels was no longer significant ($P = 0.15$ and 0.26, respectively), and the magnitude of race association decreased 34 or 55%, suggesting that the association between race and AHI levels was largely explained by poverty rate or percentage of single-female–headed households with children.

Conclusions: Neighborhood socioeconomic variables in comparison with individual-level socioeconomic indicators provides better explanations for the racial disparity in pediatric obstructive sleep apnea syndrome. Further research aimed at identifying factors that aggregate in disadvantaged neighborhoods and increase sleep apnea risk may suggest modifiable intervention targets.

Clinical trial registered with clinicaltrials.gov (NCT00560859).

Keywords: pediatrics; health disparities; poverty; risk factors

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Obstructive sleep apnea syndrome (OSAS), characterized by recurrent periods of airflow limitation or obstruction and often associated with intermittent hypoxemia and sleep fragmentation, affects between 1 and 6% of children (1). In children, it is most commonly associated with adenotonsillar hypertrophy, although it also may occur in association with obesity, craniofacial morphological risk factors, and genetic disorders. Pediatric OSAS can result in serious morbidity, with adverse effects on cognition, behavior, cardiovascular function, and somatic growth and development (2–5).

In addition to well-recognized OSAS risk factors such as obesity, studies have indicated that both race and socioeconomic status (SES) may influence pediatric OSAS. For example, African American children were found to have a three- to fourfold higher risk of OSAS than white children, independent of other factors such as obesity, premature birth, and maternal smoking (1). Severity of OSAS has also been found to be significantly associated with race (6): After controlling for potential confounders, African American race was associated with an approximately 20% increase in the apnea–hypopnea index (AHI).

There has been a long history of segregation and discrimination in the United States, and therefore it is important to note that race may be a proxy for many environmental and social determinants of health. Prior research showed that individual-level indicators did not help explain the racial disparities in OSAS outcomes. For example, Weinstock and colleagues investigated whether the relationship between African American race and OSAS severity is attenuated after considering potential mediators, including obesity, secondhand smoke, family income, maternal education, asthma status, and birth weight (6). However, analyses did not reveal sufficient evidence to suggest that any of these factors mediate the relationship between race and OSA severity.

Ancestry-related differences in craniofacial risk factors and upper airway neuromuscular characteristics could potentially account for OSA severity differences across population groups. Although craniofacial risk factors for OSA have been reported to differ by race in adults (7), these factors have not been well studied in children. However, studies of upper airway collapsibility have not shown differences between African American and white children (8).

Neighborhood socioeconomic variables are risk factors for a range of adverse behavioral, education, and health outcomes in children (9). Spilsbury and coworkers (10) found that residence in a neighborhood of severe socioeconomic disadvantage (defined by census tract poverty rate, family structure, employment, and education level) was significantly associated with OSAS after adjusting for effects of previously established risk factors including African American race and highlighted the "critical need to further assess the role of neighborhood conditions as a factor that influences children's sleep." Moreover, in a French-Canadian sample with 17% of children with African heritage, in contrast to 36% in the study by Spilsbury and colleagues (10), Brouillette and coauthors (11) reported that children with OSAS were more likely to reside in disadvantaged neighborhoods (as characterized by low family income, higher proportions of single-parent families, and greater population densities) and called for future studies to examine whether these results could be replicated in other settings.

Another potential neighborhood risk factor for OSAS is distance to major roads, which can increase exposure to pollutants, an exposure associated with elevated indices of sleep apnea severity in adults (12). Evidence also suggests that proximity to major roads is associated with elevated risk of asthma (13) and that asthma is associated with an increased risk of new-onset OSAS (14).

In the present study, we evaluated the associations of neighborhood SES and distance from major roads with OSAS severity, and we also assessed whether neighborhood-level variables attenuate the association between race and OSAS severity, using data of 774 children who underwent polysomnography screening in the Childhood Adenotonsillectomy Trial (CHAT). The study addressed these questions across six U.S. cities, providing greater generalizability than prior research, and we examined variation of quantitative measures of OSAS severity. We hypothesized that neighborhood SES indicators and distances to major roads are risk factors for OSAS severity, and that neighborhood SES attenuates the relationship between race and OSAS severity.

Methods

We analyzed data collected in the CHAT study, a randomized, controlled, multicenter clinical trial evaluating early adenotonsillectomy versus watchful waiting with supportive care in children aged 5–9.9 years with OSAS (15). Cross-sectional data collected at baseline, for both children who underwent screening and those who were randomized with available polysomnography data and addresses or geocodes, were used. Children who were not randomized did not meet eligibility criteria (because AHI was lower or higher than the OSAS severity thresholds or because they otherwise elected not to participate, as described before [15]). Institutional review board approvals were obtained from all institutions participating in this study. Written informed consent was obtained from all caregivers, and assent was obtained from children who were 7 years of age or older.

A total of 774 subjects with both neighborhood and AHI data were included in this analysis, consisting of 448 (97%) of the 464 children randomized to the CHAT study and an additional 326 children who underwent screening but were ineligible for the CHAT study. Exact addresses were available for 516 subjects. For the remaining 258 subjects, only geocodes–(representing geographic divisions used by the U.S. census instead of exact addresses) were available.

Statistical Analysis

The outcome variable of analysis was log-transformed AHI, defined as all obstructive apneas, plus hypopneas associated with a 3% or greater desaturation or arousal, with events scored following published pediatric guidelines (16). We considered the following neighborhood SES variables: poverty rate; high school dropout rate; proportion of families with related children headed by single females; and proportion of civilian, noninstitutionalized, working age (16–64 yr) males unemployed or not in the labor force. Each subject's address was geocoded using ArcGIS version 10.1 (Environmental Systems Research Institute, Redlands, CA). The Federal Information Processing Standard codes obtained in geocoding were then joined to American Community Survey 2006–2010 data at the U.S. census tract level to extract area-level sociodemographic data.

The poverty rate was calculated by the ratio of the population in poverty to the total population in a census tract. Poverty status was determined by comparing annual income with poverty thresholds that are calculated on the basis of family size, number of children, and age of householder (http://www.census.gov/topics/income-poverty/poverty.html).

The high school dropout rate was calculated by the ratio of 16- to 19-year-old population not enrolled in school and not high school graduates to the total population of 16- to 19-year-olds in a census tract. The proportion of families with related children headed by single females was calculated by the ratio of female-headed households with children to the total number of households in a census tract. The unemployment rate was calculated by the ratio of civilian, noninstitutionalized, 16- to 64-year-old males unemployed or not in the labor force to the total male population of 16- to 64-year-olds in a census tract.

We used published criteria (10, 17) to define severely distressed neighborhoods as census tracts with at least three of the following four characteristics:

1. High percentage of people living in poverty (⩾28.0%)
2. High percentage of families with related children headed by single females (⩾21.8%)
3. High percentage of 16- to 19-year-olds who are not enrolled in school and not high school graduates (⩾17.6%)
4. High percentage of civilian, noninstitutionalized males 16–64 years old who are unemployed or not in the labor force (⩾41.2%)

The threshold percentages above were determined on the basis of national mean plus 1 SD calculated from a total of 74,002 tracks.

For those subjects with exact addresses available, we obtained the spatial distance and traveling distance from each address to the nearest major road using ArcMap in ArcGIS. The major roads are defined as A1 or A2 grade roads on the basis of U.S. census feature class code.

Spearman correlation was used to measure correlation between variables. Multiple regression models were used to assess the associations between neighborhood SES variables, race, and AHI levels. Other covariates considered included the following:

- *Obesity*, defined as body mass index above the 95th percentile for age and sex, based on the growth charts developed by the CDC (https://www.cdc.gov/obesity/childhood/defining.html);
- *Asthma*, identified by caregiver report of doctor-diagnosed asthma;
- *Prematurity*, defined as a child born at less than 36 weeks of gestation;
- *Maternal education*, categorized as whether the child's mother completed a degree higher than high school;
- *Secondhand smoke exposure*, considered as positive if the primary caregiver reported at least one person smoked at least one cigarette per day in the child's home; and
- *Family income*, defined as whether annual family income is higher than $30,000.

We assessed whether associations between SES variables and AHI levels varied by study sites using both interaction tests and stratified analyses by site. We compared coefficients for race in models with and without inclusion of neighborhood SES to assess the extent to which the association between race and AHI levels was attenuated by neighborhood SES (18). All P values were two-sided.

Results

The total number of children included in this analysis was 774, among whom 448 were randomized into the CHAT study. Among these 774 children, 367 (47%) were male. Their average age was 7 (SD, 1.4) years, and 58% were African American. The remaining sample included 1% American Indian/Native Alaskan, 2% Asian, 34% white, and 6% multiracial. These children participated at six study sites (Philadelphia, PA; Cincinnati, OH; Cleveland, OH; St. Louis, MO; New York, NY; and Boston, MA) and resided in 578 unique census tracts. The median number of children per census tract was 1, with a maximum of six children from one tract.

Socioeconomic Status

Table 1 presents summary statistics for the SES variables as well as sample characteristics, overall and separately for randomized and nonrandomized children. The average rate for poverty, single-female–headed household with children, unemployment, and high school dropout were 21.1%, 21.3%, 34.3%, and 6.1%, respectively. Among the participants, 23.1% resided in a distressed neighborhood. No difference between randomized and nonrandomized children in terms of the SES variables was seen (Table 1). The AHI showed a wide range: 34.5% of children had an AHI less than 2, and 15.5% had an AHI greater than or equal to 10.

The SES variables were highly correlated among themselves (Table 2). Poverty rate was significantly positively associated with the proportion of single-female–headed household with children ($r = 0.83$; $P < 0.0001$), unemployment rate ($r = 0.80$; $P < 0.0001$), and high school dropout rate ($r = 0.30$; $P < 0.0001$), and it was negatively associated with linear distance to major road ($r = -0.26$; $P < 0.0001$) and travel distance to major road ($r = -0.34$; $P < 0.0001$). The proportion of single-female–headed households with children was positively associated with unemployment rate ($r = 0.71$; $P < 0.0001$) and high school dropout rate ($r = 0.23$; $P < 0.0001$), and it was negatively associated with distance to major road (linear distance, $r = -0.19$; $P < 0.0001$; travel distance, $r = -0.24$; $P < 0.0001$). Similarly, unemployment rate was positively associated with high school dropout rate ($r = 0.28$; $P < 0.0001$) and negatively associated with distance to a major road (linear distance, $r = -0.21$; $P < 0.0001$; travel distance, $r = -0.19$; $P < 0.0001$). The negative correlation between high school dropout rate and distance to major road was weak and did not reach statistical significance (linear distance, $r = -0.04$; $P = 0.33$; travel distance, $r = -0.08$; $P = 0.07$). Linear distance and travel distance were positively correlated ($r = 0.47$; $P < 0.0001$). The SES variables varied significantly across the six recruitment sites. The proportion of distressed neighborhood ranged from 0% (Boston) to 30.7% (Cleveland) ($P = 0.0004$).

Associations between Neighborhood-Level Socioeconomic Variables and AHI

Table 3 presents summary statistics for neighborhood-level SES variables by AHI categories. Poverty rate, percentage of single-female–headed household with

Table 1. Sample characteristics, by randomization status

Variable	Overall (*n=774*)	Randomized (*n=448*)	Nonrandomized (*n=326*)	*P* Value
Age	7.13 (1.41)	7.02 (1.40)	7.28 (1.42)	0.010
Sex, male	367 (47.5%) (n = 773)	216 (48.2%) (n = 325)	151 (46.5%)	0.66
Race, African American	433 (57.7%) (n = 750)	247 (56.7%) (n = 436)	186 (59.2%) (n = 314)	0.50
Ethnicity, Hispanic	60 (7.8%) (n = 772)	37 (8.3%)	23 (7.1%) (n = 324)	0.59
BMI z-score	0.91 (1.25) (n = 753)	0.87 (1.32)	0.98 (1.15) (n = 305)	0.35
AHI	5.70 (8.34)	6.79 (5.66)	4.21 (10.84)	<0.0001
Poverty rate (%)	21.09 (16.35)	21.46 (16.9)	20.57 (15.57)	0.82
Percentage of single-female–headed households with children	21.3 (15.29),	21.66 (16.29)	20.81 (13.81)	0.90
Unemployment rate (%)	34.28 (15.35)	33.76 (15.42)	34.98 (15.24)	0.22
High school dropout rate (%)	6.08 (9.39)	6.31 (9.77)	5.75 (8.85)	0.71
Linear distance to nearest major road, mi	0.76 (0.88) (n = 532)	0.81 (1.02) (n = 264)	0.72 (0.71) (n = 268)	0.59
Travel distance to nearest major road, mi	3.23 (2.72) (n = 532)	3.17 (2.88) (n = 264)	3.29 (2.54) (n = 268)	0.13
Severe neighborhood distress, yes (%)*	192 (24.8%)	108 (24.1%)	84 (25.8%)	0.61

Definition of abbreviations: AHI = apnea–hypopnea index; BMI = body mass index.
For continuous variables, mean (SD) values are provided, and Wilcoxon rank sum tests were performed. For categorical variables, column percent values are provided, and Fisher's exact tests were performed. In the presence of missing data, actual sample sizes for available data were included.
**See* text for definition.

children, and unemployment rate were statistically different across different AHI groups. Regression models relating AHI levels and SES variables, adjusted for age and sex, revealed similar associations (Table 4). Higher poverty rate was associated with higher AHI levels ($P = 0.008$); a 10% increase in poverty rate corresponded to a 1.09 (95% confidence interval [CI], 1.02–1.16)-fold increase in AHI levels. Similarly, a 10% increase in percentage of single-female–headed household with children was significantly associated with a 1.11 (95% CI, 1.04–1.19)-fold increase in AHI levels ($P = 0.002$).

We observed a nearly statistically significant association between unemployment rate and AHI levels ($P = 0.055$); a 10% increase in unemployment rate was associated with a 1.07 (95% CI, 1.00–1.14)-fold increase in AHI levels. We did not find significant associations between AHI levels and high school dropout rate ($P = 0.70$), linear distance to major road ($P = 0.55$), or travel distance to major road ($P = 0.19$).

We further assessed whether the associations between AHI levels and SES variables varied across sites and found that these associations were in general consistent across sites (all interaction $P > 0.18$) for all the SES variables we examined, except for the distressed neighborhood index, where significant heterogeneity in its association with AHI levels across sites was detected (interaction $P = 0.005$). More specifically, the data suggested that distressed neighborhoods were significantly associated with higher AHI levels in Cincinnati ($P = 0.009$) and in St. Louis ($P = 0.001$), whereas no significant association was observed in samples from other cities involved in the CHAT study.

For the randomized subjects, the CHAT study researchers also collected information on previously established factors that are associated with AHI levels,

Table 2. Spearman correlation coefficients among socioeconomic status variables

	Poverty Rate (%) (*n = 774*)	Percentage of Single-Female–headed Households with Children (*n = 774*)	Unemployment Rate (%) (*n = 774*)	High School Dropout Rate (%) (*n = 774*)	Linear Distance to Nearest Major Road (*n = 532*)	Road Travel Distance to Nearest Major Road (*n = 532*)
Poverty rate, %	1	0.83*	0.80*	0.30*	−0.26*	−0.34*
Percentage of single-female–headed households with children		1	0.71*	0.23*	−0.19*	−0.24*
Unemployment rate, %			1	0.28*	−0.21*	−0.19*
High school dropout rate, %				1	−0.04	−0.08
Linear distance to nearest major road, mi					1	0.47*
Travel distance to nearest major road, mi						1

**P* < 0.001.

Table 3. Socioeconomic status variables, by apnea–hypopnea index groups, unadjusted analysis

	AHI <2 (*n* = *267*)	AHI 2–5 (*n* = *248*)	AHI 5–10 (*n* = *139*)	AHI ⩾10 (*n* = *120*)	*P* Value*
Poverty rate, %					0.013
Mean (SD)	20.27 (16.03)	19.31 (15.98)	23.13 (17.46)	24.2 (16.02)	
Median (Q1, Q3)	15.68 (6.25, 32.63)	14.96 (5.41, 30.91)	20.53 (7.24, 34.14)	23.94 (11.09, 33.56)	
Percentage of single-female–headed household with children					0.007
Mean (SD)	19.91 (14.02)	19.99 (15.56)	23.75 (16.22)	24.25 (15.74)	
Median (Q1, Q3)	17.38 (7.89, 30.1)	15.75 (7.36, 28.35)	22.06 (10.76, 34.1)	22.9 (10.52, 34.89)	
Unemployment rate, %					0.002
Mean (SD)	34.37 (15.28)	31.7 (14.99)	35.94 (15.26),	37.46 (15.64)	
Median (Q1, Q3)	33.51 (21.75, 46.59)	27.67 (19.89, 42.16)	34.34 (23.75, 46.7)	36.99 (23.31, 49.89)	
High school dropout rate, %					0.22
Mean (SD)	5.92 (8.87)	5.44 (9.38)	7.06 (10.76)	6.59 (8.83)	
Median (Q1, Q3)	0 (0, 9.5)	0 (0, 7.3)	1.11 (0, 10.74)	2.88 (0, 11.15)	
Linear distance†					0.41
Mean (SD)	0.75 (0.76)	0.85 (0.99)	0.76 (1.02)	0.65 (0.75)	
Median (Q1, Q3)	0.6 (0.26, 0.89)	0.55 (0.22, 1.12)	0.48 (0.21, 0.98)	0.45 (0.26, 0.8)	
Travel distance†					0.24
Mean (SD)	3.41 (2.83)	3.25 (2.76)	3.16 (2.71)	2.78 (2.25)	
Median (Q1, Q3)	2.72 (1.78, 4.13)	2.59 (1.42, 4.06)	2.65 (1.57, 3.74)	2.34 (1.44, 3.48)	
Severely distressed neighborhood, %	66 (24.72%)	56 (22.58%)	33 (23.74%)	37 (30.83%)	0.38

Definition of abbreviation: AHI = apnea–hypopnea index.
*Kruskal–Wallis test for continuous variables and Fisher's exact test for dichotomous variables.
†n = 215, 148, 92, and 77, respectively, for AHI categories less than 2, 2–5, 5–10, and greater than 10.

including premature birth, obesity, secondhand smoke exposure, and history of asthma, as well as on indicators of household-level SES and environment, including family income and maternal education. We repeated the analysis relating AHI levels and SES variables restricted to data from randomized subjects only and found similar associations as before (Table 5, model 1). Poverty rate, percentage of single-female–headed household with children, and unemployment rate were found to be associated with AHI levels, whereas we did not find a significant association between AHI levels and high school dropout rate, linear or travel distance to major road, or severely distressed neighborhood.

Table 4. Regression models relating logarithmic apnea–hypopnea index levels and socioeconomic status variables for all screened children, adjusted for age and sex

	β-Coefficient	95% CI	*P* Value
Poverty rate, %	0.0085	0.0022, 0.0148	0.008
Single-female–headed households with children, %	0.0108	0.0041, 0.0174	0.002
Unemployment rate, %	0.0066	−0.0001, 0.0133	0.055
High school dropout rate, %	0.0021	−0.0088, 0.0131	0.70
Linear distance, mi*	−0.0450	−0.1921, 0.1021	0.55
Travel distance, mi*	−0.0320	−0.0792, 0.0153	0.19
Distressed neighborhood, yes/no			0.005†
Philadelphia, PA	−0.0581	−0.4160, 0.3000	0.75
Cincinnati, OH	0.4760	0.1209, 0.8310	0.009
Cleveland, OH	0.0215	−0.2461, 0.2890	0.16
St. Louis, MO	1.2868	0.5499, 2.0237	0.001
New York, NY	−0.4330	−1.6898, 0.8238	0.47
Boston, MA‡	—	—	—

Definition of abbreviation: CI = confidence interval.
*Based on n = 532; other analyses based on n = 773.
†*P* value for testing the interaction effect between distressed neighborhood and site on apnea–hypopnea index levels.
‡Unable to obtain estimates for Boston because the observed proportion of distressed neighborhoods was 0.

The associations between AHI levels and poverty rate, percentage of single-female–headed household with children, and unemployment rate were similar before and after adjusting for other established factors such as obesity, history of asthma, or prematurity; did not appear to be affected by adjustment for maternal education; and persisted although moderately attenuated after adjustment for family income or secondhand smoke exposure, reflecting about a 15 to –24% reduction in effect sizes and decreased levels of statistical significance (Table 5).

Associations between Socioeconomic Status Variables and Race

Table 6 presents summary statistics of SES variables by race. African American race was significantly associated with all SES variables (all $P \leqslant 0.0002$). More specifically, African American race was associated with an 18.7% (95% CI, 16.7–20.7%) increase in poverty rate, a 17.4% (95% CI, 15.6–19.3%) increase in the proportion of single-female–headed households with children, a 17.7% (95% CI, 15.9–19.6%) increase in unemployment rate, a 2.6% (95% CI, 1.3–3.9%) increase in high school dropout, 0.52 (95% CI, 0.37–0.67) miles shorter linear distance, a 1.25 (95% CI:

Table 5. Associations between log-transformed apnea–hypopnea index levels and socioeconomic status variables, with or without additional covariates*

		SES Exposures		
		Poverty Rate (%)	Single-Female–headed Households with Children (%)	Unemployment Rate (%)
Model 1		0.0052 (0.0012, 0.0093); $P = 0.011$;	0.0055 (0.0013, 0.0097); $P = 0.010$	0.0071 (0.0027, 0.0115); $P = 0.002$
Model 2	Obesity	0.0051 (0.0011, 0.0091); $P = 0.013$	0.0052 (0.0010, 0.0094); $P = 0.014$	0.0066 (0.0022, 0.0111); $P = 0.004$
	Family Income	0.0040 (−0.0005, 0.0085); $P = 0.080$	0.0042 (−0.0005, 0.0088); $P = 0.077$	0.0060 (0.0012, 0.0109); $P = 0.014$
	Secondhand smoke	0.0040 (−0.0002, 0.0082); $P = 0.060$	0.0044 (0.0001, 0.0087); $P = 0.043$	0.0059 (0.0013, 0.0104); $P = 0.012$
	Maternal education	0.0055 (0.0011, 0.0100); $P = 0.016$	0.0059 (0.0014, 0.0105); $P = 0.011$	0.0072 (0.0024, 0.0121); $P = 0.004$
	Asthma	0.0050 (0.0009, 0.0090); $P = 0.016$	0.0053 (0.0011, 0.0095); $P = 0.013$	0.0068 (0.0023, 0.0113); $P = 0.003$
	Prematurity	0.0055 (0.0014, 0.0095); $P = 0.008$	0.0054 (0.0012, 0.0096); $P = 0.011$	0.0070 (0.0026, 0.0115); $P = 0.002$
Model 3	All	0.0041 (−0.0007, 0.0088); $P = 0.094$	0.0041 (−0.0008, 0.0089); $P = 0.101$	0.0052 (0.0001, 0.0103); $P = 0.046$

Definition of abbreviation: SES = socioeconomic status.
*Analyses based on data from randomized subjects only (n = 448). Model 1 is adjusted for age and sex. Model 2 is additionally adjusted for risk factors one at a time as specified in the row heading. Model 3 is adjusted for age, sex, and the six risk factors considered in model 2. Point and 95% confidence interval estimates for the coefficient for each SES exposure and its associated *P* values are presented.

0.80–1.71)-mile shorter travel distance to a major road, and a 12.8 (95% CI, 7.4–21.9)-fold increase in the odds of being in a distressed neighborhood.

Associations among Socioeconomic Status Variables, Race, and Apnea–Hypopnea Index Levels

African American race was significantly associated with a 1.33 (95% CI, 1.08–1.64)-fold increase in AHI level ($P = 0.008$), adjusting for age and sex. The relationships between AHI levels and SES variables were consistent across African Americans and non–African Americans (all interaction *P* values >0.11).

After controlling for poverty rate or percentage of single-female–headed households with children, the association between race and AHI levels was no longer significant ($P = 0.15$ and 0.26, respectively), the magnitude of the coefficient for race decreased 34% and 55% from 0.29 to 0.19 and 0.13, respectively, suggesting that the association between race and AHI levels was largely explained by poverty rate or percentage of single-female–headed households with children. The association between race and AHI levels after controlling for unemployment rate remained nearly statistically significant ($P = 0.066$), and the magnitude of the coefficient for race decreased about 17% from 0.29 to 0.24, suggesting that the association between race and AHI levels may be partially explained by unemployment rate.

Table 6. Socioeconomic status variables, by race for all screened children, unadjusted analysis

	African American (*n* = 433)	Non–African American (*n* = 317)	*P* Value*
Poverty rate (%)			<0.0001
Mean (SD)	29.0 (15.4)	10.3 (10.8)	
Percentage of single-female–headed households with children, %			<0.0001
Mean (SD)	28.7 (14.6)	11.2 (9.5)	
Unemployment rate, %			<0.0001
Mean (SD)	41.9 (14.3)	24.2 (10.4)	
High school dropout rate, %			0.0002
Mean (SD)	7.2 (10.4)	4.5 (7.5)	
Linear distance, mi†			<0.0001
Mean (SD)	0.6 (0.5)	1.1 (1.2)	
Travel distance, mi†			<0.0001
Mean (SD)	2.7 (1.7)	4.0 (3.5)	
Distressed neighborhood (%)	175 (40%)	16 (5%)	<0.0001

*Obtained from the regression model with each socioeconomic status variable as outcome and race as independent variable.
†n = 298 African Americans and 211 non–African Americans.

Discussion

In this cross-sectional analysis of data from nearly 800 children in six cities, we found that higher poverty rate, higher proportion of single-female–headed households with children, and higher unemployment rate were associated with higher AHI levels. These associations remained after controlling for other potential confounders such as obesity, prematurity, secondhand smoke, and history of asthma. Furthermore, associations of AHI with neighborhood-level indicators of SES persisted after we considered household indicators of SES such as family income and maternal education. Adjusting for neighborhood-level SES significantly reduced the associations between AHI and race by 38 to 50%. These findings, based on a large, diverse sample of children from six U.S. cities, provides further evidence that children from neighborhoods with high poverty rates are at increased risk for OSAS and that factors associated with disadvantaged neighborhoods are more strongly associated with pediatric OSAS than race or available family-level SES measures.

Pediatric OSAS is associated with a myriad of negative health and behavioral effects, including attentional deficits and hyperactivity (4, 19–21), problems with learning and academic performance (22, 23), reduced quality of life (24–26), elevated blood pressure and cardiac remodeling (27–30), metabolic dysfunction (31, 32), and asthma exacerbations (33, 34). Several independent studies have shown that the prevalence and severity of pediatric OSAS are greater in African American children than in white children (1, 6, 35–38). Furthermore, OSAS is less likely to resolve after surgical treatment in African American children compared with others (15). The basis for this health disparity is not known, but it may include persistent exposures to environmental factors that cause nasopharyngeal inflammation, negatively influence ventilatory control, or cause sleep disruption.

Our analyses suggest that readily available family-level SES indicators do not explain racial differences in OSAS, but, in contrast, that a good portion of the "race effect" is explained by neighborhood-level SES markers. Prior research has shown that adverse environmental exposures can disproportionately cluster in poorer communities and that vulnerability to its effects may be greater in low-income populations (39). Our study, although clarifying the importance of neighborhood poverty as a risk factor for OSAS, does not identify the specific environmental variables that increase OSAS risk.

The outdoor environment may exacerbate OSAS through several mechanisms, such as by allergen or irritant exposures that stimulate adenotonsillar hypertrophy and amplify nasopharyngeal inflammation; adversely affect genioglossal muscle activity; or through adverse effects on central (brain) ventilatory and sleep–wake control mechanisms. Notably, the adenoids and tonsils enlarge in response to antigenic stimuli, and therefore exposures to airborne irritants may significantly influence lymphoid mass, which is a major determinant of upper airway patency in children. Chronic nasal congestion, exacerbated by air pollution, for example, could lead over time in a developing child to craniofacial changes that narrow the upper airway and increase the risk for OSAS.

Social and physical environmental exposures also likely influence a range of sleep outcomes (21). Studies among adult populations have shown the influence of the social neighborhood environment, including neighborhood crime, lack of safety, crowding, and low social cohesion, on sleep outcomes (22, 23, 25, 26, 40–42). Although less studied in children, there is evidence that an adverse social neighborhood environment (43, 44), as well as chaotic family routines (45, 46), adversely affect children's sleep. Insufficient sleep may exacerbate OSAS through effects on ventilatory stability (47) and by promoting a proinflammatory state (48).

The findings that neighborhood SES variables are associated with OSA severity are generally consistent with those reported by Spilsbury and colleagues (10) and Brouillette and coworkers (11). In contrast to earlier studies with samples from smaller geographic areas, our sample consists of children from 578 census tracts and six cities. Whereas the associations between SES variables and AHI levels were in general consistent across sites, the significant association between an aggregate measure of severe neighborhood distress and AHI levels was detected only in some sites. The weaker association for an aggregate index in other cities may relate to different distributions of the four measures of distressed neighborhood across the sites or to reduced power in stratified subsamples within each site.

We had hypothesized that residential proximity to major roadways would provide a surrogate marker for exposure to pollutants such as particulates, black carbon, and nitrogen oxides (49) and thus provide an opportunity to explore the potentially negative effects of air pollutants on pediatric OSAS. Prior research in adults demonstrated that exposure to particulates in the summer was associated with short-term elevation in AHI, which was postulated to occur through upregulation of inflammatory pathways (12). In the present analysis, we were unable to show this association. It is possible that the present study was underpowered to detect this putative association or that greater temporal and geographic resolution is needed to quantify relevant exposures.

Strengths and Limitations

This study has a number of strengths, including the large and diverse sample study with inclusion of children from geographically distinct neighborhoods. Measurements were collected using standardized approaches and included individual- and neighborhood-level variables.

The study also has several limitations. First, the association between neighborhood SES levels and AHI levels may be confounded by unmeasured variables that are related to both SES and AHI levels, and, as mentioned, many specific attributes of the physical and social neighborhood were not available. Only limited information on prematurity was available, precluding assessment of effects or confounding related to being born very premature (<32 wk).

Second, analyses including additional individual-level covariates was limited to a subset of subjects who were entered into the randomization phase of the CHAT study, which reduced the sample size and statistical power. Third, the addresses or geocodes represented neighborhood information at the time of study enrollment and do not provide information on the duration of exposure within given neighborhoods. The cross-sectional nature of the data does not allow us to assess the temporal aspects between neighborhood exposure and AHI, such as whether the influence of neighborhood was lagged or cumulative.

Conclusions

Residence in a disadvantaged neighborhood is associated with greater OSAS severity, suggesting a new paradigm whereby OSAS may be addressed as a public health problem with population-level interventions such as those aimed at reducing poverty rates or effects of poverty on factors that influence sleep health. Furthermore, neighborhood SES indicators in comparison with individual-level indicators appear to provide better explanations for the racial disparity in pediatric OSAS. The association between African American race and AHI level substantially decreased after we controlled for poverty rate or percentage of single-female–headed household. This suggests that, if the social and/or environmental factors associated with poverty were equalized across racial groups, the racial disparity across OSAS severity would be reduced. Further research aimed at identifying specific factors that aggregate in disadvantaged neighborhoods and increase OSAS risk also may suggest modifiable intervention targets. ■

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