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Evaluating associations between neighborhood resources and sleep health among urban-dwelling Black adolescents

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A R T I C L E I N F O

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A B S T R A C T

Objective: Despite policies that promote poor sleep environments for many Black families, the links between neighborhood characteristics and adolescent sleep health have received little attention.
Methods: Adolescents (N = 400; M age 16.39 years; 64% female at birth) who identified as Black/African American residing in a large metropolitan area and their caregivers participated. Caregivers provided demographic information and completed measures of neighborhood safety and cohesion. Home addresses were geocoded to census tract to generate COI 3.0 scores (overall, three domains and 14 subdomains). Adolescents wore actigraphs for 8 days to derive sleep indices (timing, duration, efficiency, and regularity). Linear mixed models examined associations between neighborhood variables and sleep indices adjusting for age, sex, household income, caregivers' highest level of education, and weekend status.
Results: Adolescents were underslept with sleep duration averaging 6.2 hours/night with sleep onset times of 12:57 AM and offset times of 8:17 AM averaged across 8 days. Males had later sleep onset, fewer hours of sleep, less efficient sleep, and more variability in their waketimes as compared with females. Living in a neighborhood with more educational and housing resources, less air pollution, and lower employment rates was associated with greater sleep efficiency, earlier bedtimes, and less bedtime variability.
Conclusions: Black urban-dwelling adolescents are not getting adequate sleep, and males are at greater risk. Residing in neighborhoods with fewer educational opportunities and more air pollution was linked to sleep. Future work should consider the role of policy changes and protective factors that may mitigate associations between neighborhood factors on sleep health.

Introduction

Poor sleep has widespread negative consequences on health, including cardiovascular disease,[1] obesity,[2] and depression.[3-5] Due to a "perfect storm" of biological, psychosocial, and societal influences, the majority of adolescents do not meet the recommended 8-10 hours of sleep required to support healthy functioning.[6] Black American youth report shorter duration, poorer quality, and less consistent sleep than their white peers.[7] These disparities may be due to a myriad of factors including greater exposure to discrimination,[8] but there is increased awareness of how racist policies and systemic disinvestment, such as redlining,

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blockbusting, and urban renewal, have led to vast inequities of education, employment, income, air pollution, heat levels, and home ownership in neighborhoods.[9-11] The term, sleep deserts, captures these neighborhood-level differences in physical/environmental and social features[8] that are disruptive to sleep.[9]

Research examining neighborhood environments and sleep health among Black adolescents is largely limited to socioeconomic status and exposure to community violence.[10] These single indicators fail to capture the multidimensional aspects of neighborhoods that are associated with development and health outcomes.[11] Indeed, physical/environmental features that affect sleep include ambient factors, such as noise and outdoor light at night[12] as well as built environmental factors, including greenspace.[10] Social aspects of the neighborhood environment, including safety and cohesion, is also consistently associated with adverse sleep outcomes, including later bedtimes, shorter sleep duration, and poorer sleep quality.[13-18] Indeed, urban adolescents have later bedtimes the night after a local violent crime in the surrounding neighborhood.[19] Adolescents residing in neighborhoods with higher levels of cohesion, however, experience fewer sleep problems.[20] One recent study utilizing the Adolescent Brain Cognitive Development (ABCD) sample reported that structural inequities (perceived discrimination, low school inclusivity, neighborhood safety, unmet medical needs, legal problems, material hardship, and housing insecurity) were associated with adolescents' sleep disturbance and duration, however, physical/environmental features of neighborhoods were not considered.[21]

The current study is the first to utilize both caregiver reports of neighborhood safety and cohesion along with a comprehensive multidimensional measure of social and environmental neighborhood resources holistically and geocoded at the census track level (Child Opportunity Index: COI 3.0) to examine sleep health among Black adolescents. The COI 3.0, released in 2024, includes an overall index score and three domains (education, health/environment, and social/economic), which can further be broken down into 14 subdomains.[14] To date, the only study of adolescent sleep that utilized this comprehensive measure of neighborhood resources (COI 2.0) included adolescents from affluent and predominately white (69%) households. No significant associations with the overall COI 2.0 index or the three domains were reported. Neighborhood air quality indices, however, were associated with sleep onset and offset, but not always in the anticipated direction (e.g., poorer quality associated with later waketimes).[22] Given these prior findings and the fact that this work newly emerging, we opted to utilize overall, domain and subdomain COI 3.0 scores to give a comprehensive perspective on the associations between geo-coded environmental factors and sleep health among a sample of Black adolescents residing in a large urban setting.

Using actigraphy, the current study determined if geocoded neighborhood-level resources along with caregiver reports of neighborhood cohesion and safety were associated with were associated with four dimensions of sleep health: timing, duration, efficiency, and regularity of bedtimes and waketimes.[23-25] We hypothesized that Black urban-dwelling adolescents who resided in neighborhoods with more resources as well as greater neighborhood safety and cohesion would exhibit healthier sleep (e.g., longer, more efficient, and more regularity).

Methods

Participants

Participants included 400 adolescents (*M* age = 16.39 years; 64% female at birth) who were recruited from the metropolitan area of a large Midwestern city through advertisements, presentations at schools, outreach to community organizations, and through a direct mail campaign. All enrolled adolescents were between 14-19 years of age, identified as Black and/or African American, reported at screening belonging to a low-income household (i.e., family income below two times the federal poverty threshold for their household size). Other eligibility criteria included being English speaking, having no current major chronic illnesses that necessitated taking regular medication, having no mental health disorder serious enough to warrant hospitalization in the past year, and having no pervasive developmental disorder that would make the youth unable to complete the study protocol. Participants who were currently pregnant or acutely ill were offered the option of rescheduling. Adolescent participants provided either written assent or consent (depending on age), and caregivers provided written consent to participate in all study procedures, which were approved by the Northwestern University Institutional Review Board.

Procedure

Eligible adolescents and their caregivers were invited to a laboratory visit, during which participants completed psychosocial questionnaires and health assessments while the caregiver completed interviews assessing family socioeconomic background. For eight nights beginning the night of the lab visit, youth were asked to complete daily diaries, which were completed using their preferred electronic devices (74% phone, 26% computer/tablet) at the end of each day right before bedtime. During the 8-day study period, youth also wore an actigraphy watch that assessed daily sleep. Diary completion rates were acceptable; 80% filled out at least 7 days of diaries, 14% filled out 4-6 days of diaries, and 5% filled out at least 3 days. Actigraphy compliance was good; 78% wore the watch at night for at least 7 days, 17% for between 4-6 days, and 5% for at least 3 days. Only participants (n = 324) who had at least 5 days of actigraphy data were included in the models of sleep health, and one of these participants was missing relevant covariates and was not included in the analyses resulting in a final analytic sample of n = 323. Listwise deletion was employed to achieve the analytic sample based on best practices around actigraphy data.

Measures

Actigraphy-based sleep measures

Youths' sleep was assessed objectively using the Actigraph wGT3X-BT (Actigraph, Florida). Youth were instructed to wear the actigraphy watch on their nondominant wrist for eight consecutive days, removing it only for showering or swimming. Motion was monitored in 1-minute epochs to determine whether youth were awake or asleep. Self-reported sleep and wake times were included in the daily online survey sent to youths' phones and were used to corroborate the coding of actigraphy sleep data by a team of trained coders. The ActiLife Software (v6.13.4, Actigraph) used the Sadeh algorithm, which has established validity among youth, to calculate sleep parameters.

For this study, we examined four dimensions of sleep including: timing, duration, efficiency, and regularity. Sleep timing was characterized by sleep onset and offset times that were averaged across the data collection period. Sleep duration was defined as the number of minutes scored as sleep between the sleep onset and offset interval. Sleep efficiency was also assessed using: (1) percentage of total minutes asleep and (2) minutes youth spent awake after falling asleep wake after sleep onset (WASO). Sleep regularity was examined using within-individual variability by calculating the standard deviation of: (1) sleep onset and (2) offset times across the data collection period.

Neighborhood characteristics

To assess perceptions of neighborhood, caregivers completed the My Neighborhood measure, which is comprised of 11 items rated on a 5-point Likert scale (1 = *Strongly Disagree*; 5 = *Strongly Agree*). The measure includes three subscales that assess perceptions of neighborhood cohesion (4 items), safety (3 items), and violence (4 items) that are each calculated by taking the mean of the responses to the corresponding items.[26] Cronbach's alphas for each of the subscales were 0.89 (Cohesion), 0.90 (Safety), and 0.89 (Violence).

Neighborhood resources

The *Child Opportunity Index 3.0* (COI 3.0), released in 2024, is a multidimensional index of neighborhood factors which influence healthy development in children. Comprised of 44 factors, the COI is linked to census tract geographies.[14] Home addresses collected from caregivers were geocoded to their corresponding census tract to generate several indicators from the COI 3.0 including: an overall score, three domains–*education*, *health and environment*, and *social and economic*–and 14 subdomains. The *education* domain has four subdomains: early childhood education, elementary education, secondary and postsecondary education, and educational resources. The *health and environment* domain also contains four subdomains: pollution, healthy environments, safety-related resources, and health resources. The *social and economic* domain has six subdomains: employment, economic resources, concentrated socioeconomic inequality, housing resources, social resources, and wealth. COI 3.0 data can then be compared with national, state, and metropolitan area level norms. For these analyses, nationally normed data were used to calculate z-scores for all COI indices. The overall COI z-scores can then be converted to percentiles ranging from 0-100 with a higher score indicative of more resources ("very low," 1-20, "low," 21-40, "moderate," 41-60, "high," 61-80, and "very high," 81-100). All domains and subdomains of the COI 3.0 are scored such that higher scores indicate better/higher levels of resources (e.g., higher score on pollution indicates less pollution).

Covariates

Caregivers completed forms indicating their child's age, sex (male/female), caregivers' highest level of education (up to high school/GED degree, equal/up to Bachelors' degree; more than a Bachelors' degree), as well as their annual family income. Weekend status was defined as sleep occurring on Friday and Saturday nights vs. the rest of the week.

Analytic strategy

Linear mixed models were used to assess the relationship between neighborhood indices (e.g., caregivers' reports of cohesion, safety and violence; COI 3.0 variables) and sleep health. Seven sleep variables were considered at the daily level: onset, offset, duration, efficiency and at the weekly level: bedtime and waketime variability. For each of these sleep variables, four different neighborhood variables were considered (model 1: COI overall, model 2: COI domains, model 3: COI subdomains, and model 4: caregivers' perceptions) for a total of 32 models. Based on prior research,[27] each of these models controlled for sex, age, household income, caregiver education level, and a weekday/weekend indicator. In addition, to account for differences between individuals, a random intercept was included in each of the daily models to account for nesting of the data within individuals (multiple days of sleep data for the same person). No random effects were included for census tract information because most census tracts only included a one or two individuals (see Fig. 1). Additionally, the maximum likelihood methods utilized in these linear mixed effects models, handle missing data directly under the assumption of Missing at Random. All models were fitted using the lmer function in the lme4 R package.[28]

Results

The sample included a wide distribution of participants living in different census tracts. The majority of participants (75%) lived in neighborhoods with "low" or "very low" resources as indicated by the COI 3.0 overall score (see Fig. 1). Mean scores for the main study variables for the analytic sample with actigraph data (n = 323) are listed by sex in Table 1. Over 8 days, participants fell asleep (i.e.,

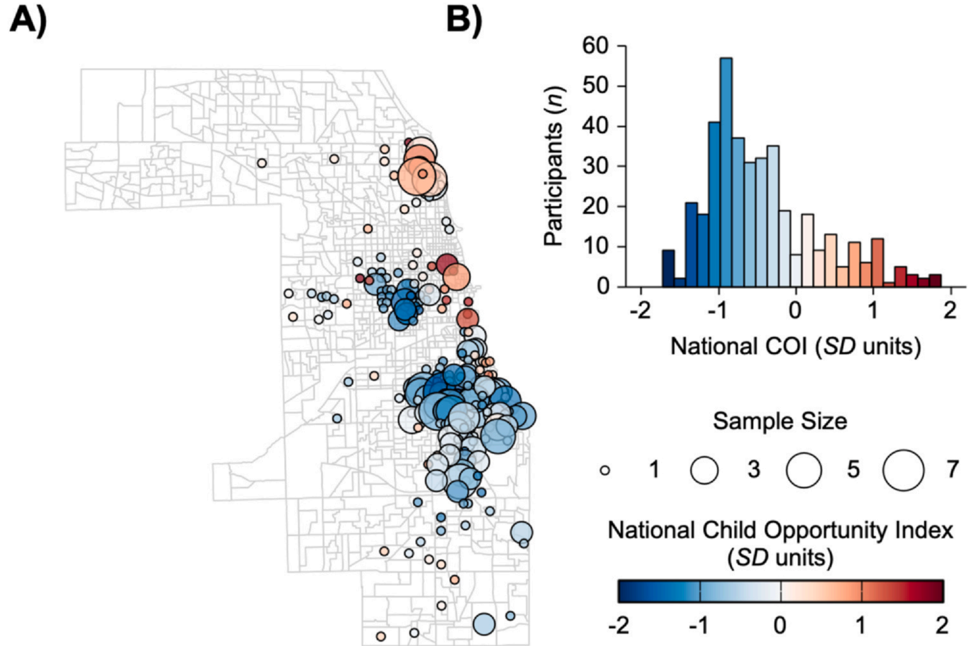

Fig. 1. Participant census tract and Child Opportunity Index (COI) 3.0. The majority of study participants reside in south and western Chicago (A) with the majority (74.9%) at low or very low level of resources based on COI z-scores relative to national averages (B). Note: In this topographical characterization of the study cohort, circles indicate the participants' census tract of residence within Cook County, Illinois, and were plotted in the center of each census tract to protect participant privacy. The number of study participants that resided within each census tract determined the size of plotted circles. Circles were colored by COI overall z-score value calculated for the census tracts of each participant

Table 1
Characteristics of the study sample by sex

Characteristics		Measures	Overall sample (n = 323) Mean (SD)	Female (n = 213) Mean (SD)	Male (n = 110) Mean (SD)
Demographics	Participants	Age, y	16.41 (1.57)	16.53 (1.58)	16.17 (1.55)
	Caregiver's education[a]	Education up to high school/GED	0.28	0.31	0.22
		Education up to bachelor's degree	0.61	0.60	0.62
		Education greater than a bachelor's degree	0.10	0.07	0.16
	Family income	Average family income, dollars	41,136 (30,143)	40,284 (27,366)	42,761 (34,915)
Sleep heath[b]	Timing	Sleep onset, 24-h time	0:57 (1:52)	0:39 (1.34)	1:30 (2:14)
		Sleep offset, 24-h time	8:17 (1:47)	8:08 (1:36)	8:34 (2:05)
	Duration	Sleep duration, min	372 (61.12)	383 (61.03)	352 (56.02)
	Sleep efficiency	% time asleep, percentile	84.75 (6.94)	85.43 (6.35)	83.43 (7.81)
		WASO, min	66.94 (32.86)	65.51 (31.74)	69.71 (34.91)
	Sleep regularity[c]	Sleep onset variability, min	94:02 (69:03)	85:47 (51:40)	109:55 (92:08
		Sleep offset variability, min	127:15 (115:0)	117:55 (104:2)	145:14 (131:6)
Caregivers' perception of neighborhood	Neighborhood characteristics	Neighborhood cohesion	3.22 (0.87)	3.20 (0.89)	3.25 (0.84)
		Neighborhood safety	2.76 (1.14)	2.76 (1.12)	2.77 (1.19)
		Neighborhood violence	2.13 (0.84)	2.09 (0.84)	2.21 (0.84)
Child Opportunity Index 3.0	COI 3.0 Domain scores	COI 3.0 Overall z-score	−0.42 (0.73)	−0.43 (0.74)	−0.38 (0.69)
		COI 3.0 Education z-score	−0.42 (0.73)	−0.42 (0.74)	−0.42 (0.71)
		COI 3.0 Health & Environment z-score	0.14 (0.55)	0.11 (0.55)	0.19 (0.55)
		COI 3.0 Social & Economic z-score	−0.59 (0.88)	−0.61 (0.91)	−0.54 (0.84)
	COI 3.0 Education subdomain scores	Early childhood education subdomain	−0.05 (0.92)	−0.06 (0.90)	−0.04 (0.98)
		Elementary education subdomain	−0.48 (0.64)	−0.48 (0.64)	−0.47 (0.63)
		Educational resources subdomain	−0.43 (0.66)	−0.44 (0.67)	−0.43 (0.63)
		Secondary & postsecondary education subdomain	−0.15 (0.69)	−0.15 (0.71)	−0.15 (0.65)
	COI 3.0 Health & Environment subdomain scores	Pollution subdomain	0.05 (0.12)	0.06 (0.11)	0.03 (0.14)
		Healthy environments subdomain	0.26 (0.26)	0.25 (0.26)	0.27 (0.25)
		Health resources subdomain	0.36 (0.56)	0.36 (0.56)	0.35 (0.56)
		Safety-related resources domain	−0.27 (0.91)	−0.33 (0.94)	−0.14 (0.86)
	COI 3.0 Social & Economic subdomain scores	Concentrated socioeconomic inequity subdomain	−0.25 (0.77)	−0.27 (0.81)	−0.22 (0.71)
		Employment subdomain	−0.29 (0.84)	−0.31 (0.86)	−0.26 (0.83)
		Economic resources subdomain	−0.93 (1.02)	−0.96 (1.07)	−0.85 (0.93)
		Housing resources subdomain	−0.16 (0.61)	−0.16 (0.62)	−0.15 (0.59)
		Social resources subdomain	−0.90 (0.85)	−0.90 (0.83)	−0.91 (0.86)
		Wealth subdomain	−0.30 (0.65)	3.2 (0.89)	3.25 (0.84)

Abbreviations: COI, Child Opportunity Index; GED, general educational development; SD, standard deviation; WASO, wake after sleep onset.
[a] Caregiver's education was calculated using frequencies.
[b] Sleep variables were aggregated across 8 d.
[c] Sleep regularity was calculated using the average standard deviation of sleep onset and offset across 8 d.

sleep onset) on average at 12:47 AM (SD = 1:57) and woke up (i.e., sleep offset) at 7:57 AM (SD = 1:58) on *weekdays* while participants fell asleep on average at 1:22 AM (SD = 2:15) and woke up at 9:14 AM (SD = 2:04) on the *weekend*. Participants were asleep (i.e., sleep duration) for approximately 373 minutes (SD = 61.12). The percent of time that participants were asleep was approximately 84.75% (SD = 6.94). After falling asleep, participants awoke for an average of 66.94 minutes (SD = 32.86). Throughout the week, participant's sleep onset time varied an average of 94.0 minutes (SD = 69.0) while their sleep offset varied 127.2 minutes (SD = 115.0).

The intraclass correlations (ICC) of the daily models indicates that there were substantial differences across individuals with ICCs ranging from around 0.2 for the duration models to near 0.5 for the timing, duration, and efficiency models. The ICC indicated how much variability is attributable to individual differences with low ICC (< 0.20) indicating people are similar across time, and a moderate to high ICC indicative of considerable within-subject variability.

Regarding sleep timing, across the four models of daily sleep onset, sex and weekend status were significantly associated with bedtimes. Using model 1 results, males went to sleep 45.9 minutes (95% CI: 20.3, 71.5 minutes) later on average than females, and participants went to sleep 35.4 minutes (95% CI: 25.7, 45.1 minutes) later on weekends as compared to weekdays. As shown in Table 2, a 1-SD increase in early childhood education programs was associated with 17.0 minutes (95% CI: 2.2, 32.0 minutes) earlier bedtimes. None of the remaining COI variables nor caregivers' perceptions variables were found to be significant. For the four models of sleep offset, only weekend status was significantly associated with waketimes. Based on model 1, participants got up an average of 74.3 minutes (95% CI: 64.8, 83.8 minutes) later on weekends as compared to weekdays. However, none of the neighborhood factors were significant.

For all four sleep duration models, sex, age, and weekend status were significantly associated with how long adolescents slept. Based on model 1 for sleep duration, males in the study slept an average of 32.4 minutes less (95% CI: 46.2, 18.7) than females. Each additional year of age was associated with 5.9 fewer minutes of sleep on average (95% CI: 10.2, 1.7), and participants averaged an extra 35.3 minutes of sleep on weekends (95% CI: 27.0, 43.6). In none of the four models of sleep duration were any of the neighborhood factors significant.

For all four models examining percentage of time asleep, age, sex, and income were significantly associated with more efficient sleep. Again, based on model 1 results, males had a 2.3% lower sleep efficiency (95% CI: 3.9%, 0.69%) on average relative to females. Age was also significantly associated with lower sleep efficiency with each additional year of age lowering sleep efficiency by an average of 0.77% on average (95% CI: 1.27%, 0.28%). Income was positively associated with this measure of sleep efficiency with each additional $10,000 in income corresponding to an average increase in 0.40% of time asleep (95% CI: 0.14%, 0.66%). In addition, several subdomains from the COI 3.0 were significantly associated with percent time asleep (see Table 3). A 1-SD decrease in air pollution was associated with a 9% increase in percent time asleep on average (95% CI: 2.42%, 16.2%). A 1-SD increase in neighborhood housing resources was

Table 2
Parameter estimates for linear mixed model of sleep onset using Child Opportunity Index subdomains

Predictor	B	β	CI (95%)	Std. CI	*p*-value
Intercept	−0.59	−0.15	(−3.02, 1.84)	(−0.33, 0.03)	.64
Sex	0.86	0.35	(0.40, 1.32)	(0.16, 0.54)	<.001***
Age	0.03	0.02	(−0.11, 0.17)	(−0.07, 0.11)	.67
Income	−0.01	−0.01	(−0.09, 0.07)	(−0.12, 0.08)	.80
Education <=BS	0.07	0.03	(−0.43, 0.57)	(−0.18, 0.24)	.78
Education >=MS	0.40	0.16	(−0.44, 1.25)	(−0.19, 0.52)	.37
Weekend sleep	0.56	0.10	(0.39, 0.73)	(0.07, 0.13)	<.001***
Early childhood education subdomain	−0.29	−0.12	(−0.53, −0.04)	(−0.21, −0.01)	.03
Elementary education subdomain	0.17	0.04	(−0.39, 0.73)	(−0.12, 0.20)	.56
Educational resources subdomain	−0.65	−0.17	(−1.63, 0.33)	(−0.45, 0.10)	.21
Secondary & postsecondary education subdomain	0.18	0.05	(−0.34, 0.70)	(−0.10, 0.20)	.52
Pollution subdomain	1.32	0.07	(−0.56, 3.20)	(−0.03, 0.18)	.19
Healthy environments subdomain	0.35	0.04	(−0.86, 1.57)	(−0.09, 0.17)	.58
Health resources subdomain	0.08	0.02	(−0.43, 0.58)	(−0.10, 0.14)	.77
Safety-related resources domain	−0.07	−0.02	(−0.42, 0.29)	(−0.15, 0.12)	.73
Concentrated socioeconomic inequity subdomain	0.96	0.30	(−0.03, 1.94)	(−0.02, 0.61)	.07
Employment subdomain	−0.29	−0.10	(−0.93, 0.34)	(−0.33, 0.13)	.38
Economic resources subdomain	−0.43	−0.17	(−1.09, 0.24)	(−0.46, 0.12)	.23
Housing resources subdomain	0.55	0.14	(−0.04, 1.15)	(−0.02, 0.29)	.08
Social resources subdomain	−0.06	−0.02	(−0.65, 0.53)	(−0.23, 0.19)	.85
Wealth subdomain	0.14	0.03	(−0.56, 0.83)	(−0.15, 0.22)	.71
Random effects					
σ^2	3.005				
$\tau 00$	2.863				
ICC	0.488				
N	314				
Observations	2269				
Marginal R^2/Conditional R^2	0.040/0.509				

Abbreviations: B, unstandardized coefficient; BS, Bachelor of Science; CI, confidence interval; ICC, intraclass correlation coefficient; MS, Master of Science; β, standardized coefficient; σ^2, within-individual variance; $\tau 00$, between-individual variance.
***≤.001.

Table 3
Parameter estimates for linear mixed model of percentage of time spent asleep using Child Opportunity Index subdomains

Predictor	B	β	CI (95%)	Std. CI	*p*-value
Intercept	94.99	0.15	(86.04, 103.94)	(−0.02, 0.33)	0***
Sex	−2.35	−0.25	(−4.03, −0.66)	(−0.44, −0.06)	.01**
Age	−0.78	−0.13	(−1.30, −0.26)	(−0.22, −0.04)	.01**
Income	0.44	0.14	(0.16, 0.72)	(0.046, 0.23)	.00***
Education <=BS	−0.79	−0.08	(−2.63, 1.05)	(−0.29, 0.12)	.42
Education >=MS	−1.32	−0.14	(−4.44, 1.80)	(−0.48, 0.20)	.42
Weekend sleep	0.51	0.02	(−0.17, 1.18)	(−0.01, 0.06)	.14
Early childhood education subdomain	0.39	0.04	(−0.52, 1.30)	(−0.06, 0.13)	.42
Elementary education subdomain	−1.43	−0.10	(−3.49, 0.62)	(−0.24, 0.05)	.19
Educational resources subdomain	0.33	0.02	(−3.29, 3.95)	(−0.24, 0.29)	.86
Secondary & postsecondary education subdomain	0.81	0.06	(−1.11, 2.73)	(−0.09, 0.21)	.43
Pollution subdomain	9.35	0.13	(2.42, 16.26)	(0.03, 0.23)	.01**
Healthy environments subdomain	0.31	0.01	(−4.18, 4.79)	(−0.12, 0.13)	.90
Health resources subdomain	−0.98	−0.06	(−2.82, 0.87)	(−0.17, 0.06)	.32
Safety-related resources domain	0.86	0.08	(−0.46, 2.17)	(−0.05, 0.20)	.22
Concentrated socioeconomic inequity subdomain	1.75	0.14	(−1.89, 5.37)	(−0.16, 0.45)	.36
Employment subdomain	−2.37	−0.22	(−4.72, −0.02)	(−0.44, 0.01)	.06
Economic resources subdomain	−0.66	−0.07	(−3.11, 1.79)	(−0.34, 0.20)	.61
Housing resources subdomain	2.78	0.18	(0.59, 4.97)	(0.03, 0.33)	.02*
Social resources subdomain	−1.10	−0.10	(−3.27, 1.07)	(−0.30, 0.10)	.34
Wealth subdomain	0.12	0.01	(−2.45, 2.67)	(−0.17, 0.18)	.93
Random effects					
σ^2	46.08				
$\tau 00$	38.69				
ICC	0.46				
N	276				
Observations	1981				
Marginal R^2/Conditional R^2	0.078/0.499				

Abbreviations: B, unstandardized coefficient; BS, Bachelor of Science; CI, confidence interval; ICC, intraclass correlation coefficient; MS, Master of Science; β, standardized coefficient; σ^2, within-individual variance; $\tau 00$, between-individual variance.
*** <.001, ** <.01, * <.05.

associated with a 2.78% increase in percentage of time asleep on average (95% CI: 0.59%, 4.97%).

Another set of models examined sleep efficiency using WASO, and for these four models a log transformation was used to better handle outliers in this variable, specifically we considered the log (awakening+1) to avoid taking the log of 0. Income and weekend status were both significantly associated with WASO with each additional $10,000 of income related to a 3.12% reduction in WASO on

Table 4
Parameter estimates for linear mixed model of wake after sleep onset (WASO) using Child Opportunity Index subdomains

Predictor	B	β	CI (95%)	Std. CI	*p*-value
Intercept	3.59	1.18	(2.89, 4.28)	(1.13, 1.22)	0***
Sex	0.08	0.02	(−0.05, 0.21)	(−0.02, 0.07)	.26
Age	0.03	0.03	(−0.01, 0.07)	(0.00, 0.05)	.11
Income	−0.03	−0.04	(−0.06, −0.01)	(−0.06, −0.01)	.00**
Education <=BS	0.04	0.01	(−0.11, 0.18)	(−0.04, 0.06)	.62
Education >=MS	0.05	0.02	(−0.20, 0.29)	(−0.07, 0.10)	.72
Weekend sleep	0.06	0.01	(−0.00, 0.12)	(0.00, 0.02)	.06
Early childhood education subdomain	−0.03	−0.01	(−0.10, 0.04)	(−0.03, 0.02)	.42
Elementary education subdomain	0.15	0.03	(−0.01, 0.31)	(−0.01, 0.07)	.08
Educational resources subdomain	−0.03	−0.00	(−0.32, 0.25)	(−0.07, 0.07)	.82
Secondary & postsecondary education subdomain	−0.02	−0.01	(−0.17, 0.13)	(−0.05, 0.03)	.77
Pollution subdomain	−0.63	−0.03	(−1.17, −0.09)	(−0.06, −0.00)	.03*
Healthy environments subdomain	0.03	0.01	(−0.32, 0.38)	(−0.03, 0.04)	.88
Health resources subdomain	0.06	0.02	(−0.08, 0.21)	(−0.01, 0.05)	.42
Safety-related resources domain	−0.05	−0.01	(−0.16, 0.05)	(−0.04, 0.02)	.33
Concentrated socioeconomic inequity subdomain	−0.14	−0.04	(−0.42, 0.15)	(−0.12, 0.04)	.36
Employment subdomain	0.19	0.04	(0.01, 0.38)	(−0.01, 0.10)	.05*
Economic resources subdomain	−0.00	0.014	(−0.19, 0.19)	(−0.06, 0.08)	.98
Housing resources subdomain	−0.23	−0.06	(−0.40, −0.05)	(−0.09, −0.02)	.01**
Social resources subdomain	0.08	0.02	(−0.09, 0.25)	(−0.03, 0.07)	.36
Wealth subdomain	0.03	0.01	(−0.17, 0.23)	(−0.04, 0.05)	.80
Random effects					
σ^2	0.381				
τ00	0.226				
ICC	0.373				
N	314				
Observations	2269				
Marginal R^2/Conditional R^2	0.024/0.387				

Abbreviations: B, unstandardized coefficient; BS, Bachelor of Science; CI, confidence interval; ICC, intraclass correlation coefficient; MS, Master of Science; β, standardized coefficient; σ^2, within-individual variance; τ00, between-individual variance.
***≤.001, **≤.01, *≤.05.

Table 5
Parameter estimates for linear mixed model of sleep onset variability using Child Opportunity Index domains

Predictor	B	β	CI (95%)	Std. CI	*p*-value
Intercept	88.23	−0.27	(3.99, 172.46)	(−0.49, −0.05)	.04*
Sex	22.10	0.32	(5.88, 38.32)	(0.08, 0.55)	.01**
Age	0.056	E <0.001	(−4.95, 5.06)	(−0.11, 0.11)	.98
Income	−3.53	−0.15	(06.21, −0.85)	(−0.27, −0.04)	.01**
Education <=BS	15.58	0.22	(−1.99, 33.15)	(−0.03, 0.48)	.08
Education >=MS	12.10	0.17	(−17.24, 41.44)	(−0.25, 0.60)	.42
COI 3.0 Education	−23.41	−0.25	(−42.27, −4.56)	(−0.44, −0.05)	.02*
COI 3.0 Health	−2.45	−0.02	(−20.80, 15.90)	(−0.17, 0.13)	.79
COI 3.0 Social & Economic	14.21	0.18	(−1.72, 30.15)	(−0.02, 0.38)	.08

Abbreviations: B, unstandardized coefficient; BS, Bachelor of Science; CI, confidence interval; COI, Child Opportunity Index; MS, Master of Science; β, standardized coefficient.
* < .05, ** < .01.

average (95% CI: 1.14%, 5.08%). On weekends, adolescents in this study were awake approximately 5.98% more minutes after going to bed than on weeknights (95% CI: 0.26%, 12.42%). Caregivers' perceptions of neighborhoods were unrelated to this index of sleep efficiency, but several of the COI subdomains variables accounted for variability in WASO (see Table 4). A 1-SD decrease in air pollution was associated with a 46.6% reduction in awakening minutes on average (95% CI: 8.31%, 68.84%). A 1-SD increase in neighborhood housing resources was associated with a 20.18% decrease in awakening minutes on average (95% CI: 5.29%, 32.73%), and greater employment rate was associated with a 21.42% increase in awakening minutes on average (95% CI: 1.04%, 45.85%).

In most of the sleep regularity models, the covariates were not associated with either bedtime or waketime variability across the week. However, in models 2-4 for sleep onset variability, sex and income were significantly associated with waketime variability. Based on model 2, the average variability in sleep onset among males increases by 22.1 minutes (95% CI: 5.9, 38.3 minutes) and an extra $10,000 in household income is associated with an average decrease of 3.5 minutes (95% CI: 0.85, 6.2 minutes). This indicates that females and individuals from wealthier households have more regular bedtimes. Further, the COI Education domain was associated with bedtime variability such that a 1-SD increase was associated with an average decrease of 23.4 minutes (95% CI: −42.3, 4.6 minutes) in the variability of sleep onset across the week, meaning adolescents residing in neighborhoods with more educational resources had more regular bedtimes (see Table 5). Neighborhood factors were not significant in any of the four models of waketime variability.

Discussion

The majority of adolescents do not meet the recommended 8-10 hours of sleep required to support healthy cognitive and psychological functioning.[6,29-31] Similar to other health indicators, however, disparities exist in sleep, with Black adolescents experiencing poorer sleep compared to their white non-Hispanic peers.[7] Results from this study indicated that Black adolescents in a large midwestern metropolitan area are sleeping an average of 6 hours of sleep/night. Although napping was not considered in these analyses, the total amount of sleep that adolescents are getting is far less than is recommended. Sleep quality was also poorer than what is typically expected with less than 85% efficiency on average, and adolescents spending approximately an hour awake each night after sleep onset. Adolescents' sleep was also highly variable with sleep onset varying by 35 minutes on average from weekday to weekend with wake times being even more variable (more than 77 minutes variation on average). Males had later sleep onset, fewer hours of sleep, less efficient sleep and were more significantly more variable in their waketimes as compared to females. The fact that males sleep was significantly more compromised during adolescence as compared with females suggests Black males may face a unique set of challenges to healthy sleep. Additionally, although short sleep duration has been studied extensively as a predictor of health and wellbeing, these findings underscore the importance of sleep consistency, or regularity in sleep, as a critical marker of sleep health warranting further inquiry and intervention.[3,32]

Geocoded indices (i.e., indices based on a geographic location; e.g., census tract, zip code) that can be linked to other datasets, have been used in public health disparities research to contextualize public health surveillance data.[33] Black adolescents have historically been marginalized and due to racist policies are more likely to live in neighborhoods that have social, physical, and environmental characteristics that are detrimental to sleep are not sleep promotive.[9] The use of geocoded indices, such as the COI, which has been designed specifically to examine inequities in the distribution of neighborhood resources attempts to quantify the downstream effects of racist policies on childhood health and well-being, but its association with sleep outcomes among Black adolescents is very limited.[22]

Results from this study provide some evidence that the neighborhood resources are linked to certain aspects of sleep among urban-dwelling Black adolescents. Similar to a study of predominately white adolescents from affluent households,[22] the findings from the current study reported that after accounting for age, sex, income, education, and weekend status, adolescents who resided in areas with higher levels of air pollution had poorer sleep efficiency as assessed with two different indices. The research literature indicates increased exposure to both ambient air pollution as well as indoor air pollution is associated with increased respiratory sleep concerns, as well as worse sleep outcomes among children and adolescents.[34]

Unlike the prior study,[22] living in neighborhoods with more housing resources was linked to more efficient sleep including a greater percentage of time asleep and fewer minutes awake after sleep onset. The housing subdomain of the COI 3.0 includes census-tract level data capturing access to broadband in the home as well as crowded housing. It is noteworthy that this subdomain was associated with less efficient sleep even after accounting for household income and education. One counterintuitive finding was the fact that greater neighborhood employment was linked to more time awake after sleep onset (WASO), one index of sleep efficiency. These findings warrant further investigation in future research on sleep deserts to fully consider how neighborhood-level resources affect household sleep environments and the potential buffering role of the home environment in the face of neighborhood challenges.[35]

Adolescents who live in neighborhoods with more education resources overall exhibited less variability in sleep onset, and having greater access to early childhood education resources was associated with earlier bedtimes for adolescents. While less sleep variability has been associated with better academic performance[36] and lower reported school-based pressure,[37] the relation between sleep variability and educational opportunities at the neighborhood level have not been found to date. Having more opportunities to pursue education in your immediate surrounds may create more consistency in routines resulting in less variable bedtimes.

Another interesting finding that emerged from this study is the lack of significant associations between any caregivers' perceptions of neighborhood characteristics and adolescent sleep health. Similarly, a study of adolescents in California found no significant effects for subjective reports of neighborhood cohesion, safety for actigraph-assessed sleep health outcomes.[12] Although the majority of studies to date have focused on perceptions of neighborhood characteristics including safety and cohesion, these findings using actigraphy data, coupled with prior work, suggests that adolescents' sleep may be less affected by aspects of the neighborhood that are noticed by caregivers.

Adolescents often have greater capacity to choose activities and bedtimes. They also have more access to electronic media and heighted academic or extracurricular demands, all of which may all disrupt sleep.[3] By 18 years of age, parent directed bedtimes are rarely set.[38] However, even as adolescents develop more autonomy over their discretionary time activities, including use of electronic media which often delays bedtime and increases arousal prior to bed,[39,40] parental rules and monitoring may serve to be protective for sleep consistency.[41] Additionally, adolescents living in urban areas who report having dinner with their family more days a week and those who report higher levels of positive parenting also had longer sleep duration.[42] Future work should examine the relation between family-level factors and neighborhood factors as they related to adolescent sleep outcomes.

Several limitations of the current study are worth noting. First, the COI relies on census tract data and may not capture an adolescent's more proximal surroundings. Second, the data presented in this paper is cross-sectional not allowing for consideration of causal effects. Finally, the comprehensive approach to assessing neighborhood effects including utilizing the overall score, domains and 14 subdomains of the COI 3.0 along with caregivers' reports resulted in a large number of models which may have led to spurious findings. However, given the pattern of findings were replicated across sleep indices and generally fell in the expected direction in all but one instance suggests that these were not random effects.

Conclusions

Sleep health, incorporates multiple sleep dimensions beyond sleep duration (e.g., timing, efficiency), and has been a focus of efforts to improve overall public health and inequities.[43-46] However, not only do adolescents struggle to maintain healthy sleep, poor sleep in adolescence is associated with continued poor sleep and other health consequences in adulthood,[47-49] making this period a critical window of opportunity for intervention. Further work is needed to enhance our understanding of Black urban-dwelling adolescents' sleep as it occurs in the real world as well as neighborhoods' influence in order to inform personalized interventions of sleep health in this understudied population.

Author contributions

Amy M. Bohnert: Conceptualization, Analyses, Writing - original draft preparation and revisions. **Maureen T.S. Burns**: Data curation, Analyses, Writing - original draft preparation and revisions. **Julianna P. Adornetti**: Data curation, Analyses, Writing - original draft and revisions. **Gregory J. Matthews**: Data curation, Writing - revisions. **Patrick L. Tu**: Data curation, Data visualization, Writing - original draft. **Michelle A. Chen**: Data curation, Investigation. **Hee Moon**: Investigation, Data curation, Supervision, Project administration. **Jungwon Kim**: Investigation, Data curation, Supervision. **Edith Chen**: Conceptualization, Methodology, Funding acquisition, Writing - review & editing and revisions.

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Data availability

Because the participants who provided the data were informed that their study-related information would be kept confidential, the data for this study are not publicly available. The data can be available upon request with IRB approval and a data use agreement.

Declaration of conflicts of interest

No conflicts of interest.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, generative AI (ChatGPT) was used to create regular expressions in the R code to calculate the COI scores. After using this service, all code was reviewed and approved and we take full responsibility for the content of the publication.

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