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Original Article

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Neighborhood disadvantage is associated with actigraphy-assessed sleep continuity and short sleep duration

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Abstract

Study Objectives: Neighborhood disadvantage has been linked to poor sleep. However, the extant research has primarily focused on self-reported assessments of sleep and neighborhood characteristics. The current study examines the association between objective and perceived neighborhood characteristics and actigraphy-assessed sleep duration, efficiency, and wakefulness after sleep onset (WASO) in an urban sample of African American adults.

Methods: We examined data from predominantly African American adults (n = 788, mean age 55 years; 77% female) living in two low-income neighborhoods. Perceived neighborhood characteristics included safety, social cohesion, and satisfaction with one's neighborhood as a place to live. Objective neighborhood conditions included walkability, disorder, street lighting, and crime levels. Sleep duration, efficiency, and WASO were measured via 7 days of wrist-worn actigraphy. Analyses estimated each of the sleep outcomes as a function of perceived and objective neighborhood characteristics. Individual-level sociodemographics, body mass index, and psychological distress were included as covariates.

Results: Greater perceived safety was associated with higher sleep efficiency and shorter WASO. Higher levels of crime were associated with poorer sleep efficiency and longer WASO, but these associations were only evident in one of the neighborhoods. Several interactions emerged suggesting that the association between neighborhood characteristics and sleep outcomes differed by neighborhood.

Conclusions: Both how residents perceive their neighborhood safety and their exposure to objectively measured crime have implications for sleep continuity. These findings suggest that neighborhood conditions may contribute to disparities in sleep health.

Key Words: actigraphy; neighborhood disadvantage; disparities; sleep; socioeconomic status; crime

Statement of Significance

Living in a socioeconomically disadvantaged neighborhood may contribute to pervasive disparities in sleep and other morbidities. This study is among the first to examine objective and perceived assessments of neighborhood conditions in relation to objectively measured sleep in a high-risk sample of predominantly low-income, African American residents. Higher crime and lower perceived safety were associated with poorer sleep efficiency and longer WASO. Disturbed sleep may be an important pathway linking neighborhood characteristics and adverse health outcomes.

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Introduction

Neighborhood characteristics are increasingly recognized as important risk factors for a host of physical and mental health morbidities [1, 2]. Residing in neighborhoods with higher levels of adverse characteristics such as crime and disorder or lower levels of socioeconomic status, social cohesion, walkability, and/or access to healthy foods has been associated with cardiometabolic risk factors including higher body mass index (BMI) [3, 4], diabetes [5], and hypertension [6, 7]. However, the mechanisms underlying these associations are not fully understood.

A parallel line of research has identified short, disrupted, irregular, and/or poor quality sleep as important risk factors for numerous health conditions, including obesity, cardiometabolic dysregulation, physical limitations, poorer immune functioning, and poor self-reported health [8–11]. Thus, sleep represents an important potential mechanism through which neighborhood environments may influence physical and mental health [12–15].

An emergent area of research has examined associations between the conditions of one's neighborhood of residence and either sleep quality or duration [13, 16–19]. In general, disadvantaged neighborhood conditions (e.g. higher levels of crime and/or noise; lower levels of social cohesion, and/or walkability) are associated with shorter sleep duration and poorer sleep quality [12–14, 20–23]. Importantly, most prior work in this area has focused exclusively on perceived indicators of neighborhood conditions. Perceptions of neighborhood conditions are important indicators of an individual's stress appraisal related to their neighborhood environments [24], and some studies suggest that perceived neighborhood conditions are even more strongly associated with health outcomes than observed characteristics [25–27]. Despite these important contributions, such reports are subject to a number of reporting biases, which is particularly problematic for studies that also rely on the subjective reporting of sleep; an individual's tendency toward positive or negative valence could influence perceptions of both sleep and their neighborhood environment [28]. In fact, most prior studies of neighborhood-sleep associations have also relied on subjective, self-reported assessments of sleep [12, 14, 18]. Of the few studies that have included objective measures of sleep, via wrist-worn actigraphy methods, the findings have been somewhat mixed depending on the sleep outcome, perhaps due to differences in the age of the sample as well as the methodology to assess sleep and neighborhood conditions [16, 19]. For example, in one study of children in Alabama, higher levels of neighborhood economic deprivation were associated with shorter sleep duration and poorer sleep efficiency [16]. In a study of older adults from the Multi-Ethnic Study of Atherosclerosis (MESA) study, higher levels of social cohesion and safety were associated with longer sleep duration and earlier sleep midpoint, whereas neighborhood social factors were not associated with indicators of sleep continuity, including sleep efficiency or sleep fragmentation [19]. In the Sueño ancillary study of the Hispanic Community Health Study/Study of Latinos (HCHS/SOL), lower levels of perceived safety were associated with greater risk of sleeping less than 6 hr per night (based on actigraphy), after covariate adjustment [29].

Finally, relatively little research has focused on neighborhood-sleep associations within low-income African American populations. Such research is important for two major reasons. First, African Americans face relatively greater risk for sleep problems, including short sleep duration, more fragmented sleep, and worse sleep quality, relative to non-Hispanic Whites [30–34]. Second, African Americans are disproportionately likely to live in disadvantaged neighborhoods compared with non-Hispanic Whites [35]. Furthermore, some evidence suggests that sleep-health associations consistently identified among non-Hispanic Whites (e.g. associations of sleep duration and BMI) [36] may be less consistent in African Americans [37].

The current analyses make several unique contributions to the existing literature: (1) examining associations of multiple perceived and objective indicators of neighborhood characteristics; (2) analyzing associations of these characteristics with actigraphy-assessed sleep duration, as well as two important indicators of sleep continuity, sleep efficiency, and wakefulness after sleep onset (WASO); and (3) exploring these associations in a sample of low-income African Americans in two comparable urban neighborhoods.

We hypothesized that lower levels of perceived neighborhood social cohesion, safety, and satisfaction, as well as more negative objectively measured neighborhood characteristics (i.e. higher crime rates, greater neighborhood disorder, and increased exposure to street lighting) would be associated with poorer sleep efficiency, longer WASO, and shorter sleep duration, after adjustment for other known risk factors for sleep disturbances, including individual-level SES, psychological distress, and BMI.

Methods

Study population and participants

The PHRESH Sleep study (PHRESHZzz) is part of a set of studies that build upon the original study of Pittsburgh Hill/Homewood Eating, Shopping, and Health (PHRESH), which recruited a random sample of households in two low-income, predominantly African American neighborhoods in Pittsburgh, Pennsylvania. One neighborhood (the Hill District) has and continues to undergo substantially more neighborhood economic revitalization, including housing and greenspace improvements and renovation, compared with the other neighborhood (Homewood). PHRESHZzz is designed to investigate how changes in the neighborhood environment may influence sleep and other health behaviors. This study uses baseline data collected in Spring 2013, which was collected prior to major greenspace and housing renovations. Data collection included neighborhood-level built and social characteristics, and detailed individual-level data, collected during an in-home interview. All study protocols were approved by RAND's Institutional Review Board.

Actigraphy-based sleep outcomes

We used the Actigraph GT3x+, which has been validated to measure sleep/wake rhythms relative to both polysomnography and Actiwatch [38–41]. Participants were asked to wear the accelerometer on their wrist continuously for 7 consecutive days. Based on prior research suggesting the minimum number of nights required to establish reliable sleep-wake patterns via actigraphy, participants with <4 nights of data were excluded from the analyses (N = 210). The average number of nights of actigraphy for the analytic sample was 5.96, SD = 0.52, range = 4.00–7.00. Data were separated into sleep and wake periods using data on bedtimes and waketimes from daily sleep diaries, and further verified by visual inspection of the actigraphy tracings. Sleep data were then scored using the Cole–Kripke algorithm [42] to determine sleep and wake periods, and to derive the primary sleep outcomes (i.e. sleep efficiency, WASO, and duration). Sleep outcomes were averaged across all nights during each assessment period to provide an assessment of habitual sleep patterns across all available nights of data.

Sleep efficiency represents the total duration of objectively measured sleep divided by the total time in bed, as reported in sleep diaries and visual inspection of actigraphy records, with higher values indicating better sleep continuity. Sleep efficiency was analyzed as a continuous measure.

WASO was defined as the total number of minutes scored as wake (based on movement) after sleep onset based upon the Cole–Kripke algorithm. WASO was analyzed as a continuous variable, with higher values indicating longer WASO.

Sleep duration is the total amount of time spent sleeping during the participant's time in bed, assessed by actigraphy. Based on prior literature demonstrating that both short [43] and long [44] sleep durations are associated with adverse health outcomes, secondary analyses analyzed total sleep time using three categories: <7 hr (N = 605); 7 to 9 hr (N = 159), inclusive; and >9 hr (N = 24). Notably, given the small number of "long sleepers" in this sample (only 3% of sample), the analyses comparing the reference (7–9 hr) and >9 hr group are exploratory.

Perceived neighborhood-level exposures

We included three measures of perceived neighborhood characteristics: social cohesion, perceived safety, and neighborhood satisfaction.

Social cohesion was assessed with a validated, five-item Likert-scale, ranging from 1 (strongly agree) to 5 (strongly disagree) [45]. Participants were asked how strongly they agree or disagree with various statements (e.g. "People around here are willing to help their neighbors"; "This is a close-knit neighborhood") (Cronbach's α = 0.84) [45]. Higher scores indicate greater social cohesion.

Perceived safety was measured by averaging four items rated on five-point Likert scales, ranging from 1 (strongly agree) to 5 (strongly disagree), with higher scores indicating greater perceived safety [46]. Participants were asked how strongly they agree or disagree with various statements (e.g. "You feel safe walking in your neighborhood during the day," "You feel safe walking in your neighborhood at night," "Your neighborhood is safe from crime," "Violence is a problem in your neighborhood" (reverse-coded) (Cronbach's α = 0.71).

Neighborhood satisfaction was assessed by a single-item rated on a five-point Likert scale, asking participants, "All things considered, would you say you are very satisfied, satisfied, dissatisfied, very dissatisfied or neutral - neither satisfied nor dissatisfied with your neighborhood as a place to live?" [47]. Higher scores indicate greater neighborhood satisfaction.

Objective neighborhood-level exposures

In both neighborhoods, trained data collectors conducted audits on 613 street segments. Segments (both sides of a street between two cross streets) were randomly selected from both neighborhoods, with an oversampling of segments where there was anticipated change. Data collectors walked the length of each segment to complete the audits, adapted from the Bridging the Gap Street Segment Tool [48, 49]. We audited a 25 per cent sample of street segments within a quarter mile of the participant's residence [50]. Aspects of neighborhoods that were hypothesized to be relevant for sleep were selected for construction of derived variables.

Specifically, we created several scores that capture objectively-measured aspects of neighborhood disorder, street lighting, and walkability. The disorder score is the sum of following items present in the street: lack of aesthetics (e.g. art), litter, vacant housing, bars on windows, broken windows, and the data collector reporting that they did not feel safe walking on the segment. Cronbach's α for objective neighborhood disorder is 0.77. Higher scores indicate greater disorder. The street lighting score is based on the dichotomous variable where 1 indicates any lighting on either side of the street and 0 indicates no lighting. A higher score represents a greater proportion of street segments with any street lighting. Based on prior research linking greater neighborhood disorder [13] or greater exposure to street lighting [51] with sleep disturbances, we hypothesized that these objective measures of disorder and lighting would be associated with shorter sleep duration, poorer sleep efficiency, and longer WASO.

We derived the walkability index [49] from neighborhood street segment observations in both neighborhoods. The walkability index was designed based on the social-ecological model and evidence that sidewalks and other street characteristics were associated with physical activity/walking [52–54]. Specifically, the walkability index was composed of the following items: traffic signs at the intersection (4 points) pedestrian crossings (2 points), sidewalks (10 points), lighting (2 points), transit (2 points), and mixed use (2 points). For each street segment, we summed the items and used the weighted average across the street segments (Cronbach's α = 0.55) and the scale ranges from 0 to 22, with higher scores indicating greater walkability [49]. Consistent with limited prior research demonstrating a link between less walkable neighborhood environments and increased risk for sleep disturbance, we predicted that lower walkability would be associated with poorer sleep efficiency, longer WASO, and shorter sleep duration.

To create participant-level exposures we created a weighted average of the street segment-level measures, using the sampled segments within a quarter mile of a participant's home with weights proportional to the length of each segment. Segments with a missing value on a measure were omitted from the participant's buffer-level calculation for that measure.

Neighborhood-level crime exposures

Using incident-level crime data provided by the City of Pittsburgh police department and ArcGIS 10.2 software, we calculated street network distances from each household to each approximate crime location. We were able to geocode 95 per cent of the incidents using the address information from the raw data. For each household, we summed the total number of 2012 crimes that occurred within a 1 km network distance, to arrive at the household buffer for crime in 2012. The 1 km distance was chosen because this has been used in prior neighborhoods research [55, 56] and because this is considered "walking distance" (or within 10 min by walking). We predicted that higher levels of crime would be associated with poorer sleep efficiency, longer WASO, and shorter sleep duration.

Individual-level covariates

Variables that are known to be associated with sleep disturbances and/or neighborhood disadvantage were selected a priori and included as covariates. In particular, sociodemographics including age, gender, education (categorized into less than high school [referent], high school diploma, and some college/bachelor's degree), marital/cohabitation status (married or living with a partner versus living alone), household annual income, length of time in neighborhood, and presence of children in the home were collected via interview. In addition, given known associations between sleep disturbances and symptoms of depression and anxiety [57], we statistically controlled for a general measure of psychological distress, using the validated Kessler 6 instrument (Cronbach's $\alpha = 0.86$), to evaluate the independent associations between neighborhood characteristics and sleep outcomes [58]. BMI was calculated from interviewer-measured height (without shoes) and weight as weight in kg divided by height in m^2. To account for unmeasured differences across neighborhoods that could confound associations between neighborhood characteristics and sleep, we also adjusted for neighborhood, using a binary indicator of Hill District versus Homewood. We did not include race/ethnicity as a covariate because 96 per cent of the sample self-identified as Black or African American.

Analytic sample

Of the 1051 participants who were part of the study cohort in 2013, we excluded residents who no longer lived in one of the two study neighborhoods (Hill District, Homewood; $n = 48$), participants with <4 nights of actigraphy-measured sleep due to missing accelerometry data or incomplete sleep logs ($n = 210$), or who were missing covariates ($n = 5$). Therefore, the sample size for analysis with perceived neighborhood-level exposures was 788. For analyses with objective neighborhood-level measures, we excluded those missing street segment data from street audits ($n = 65$) for a sample size of 723. Finally, for analyses including neighborhood-level crime exposures, we excluded those missing crime data ($n = 13$) for a sample size of 775 adults. Those excluded due to missing/invalid data were on average 2 years younger than the analytic sample ($p = 0.04$). The analytic sample did not differ significantly from the excluded sample on any other study variables.

Statistical analyses

We performed descriptive analyses and multivariable models using SAS software, Version 9.4 (SAS Institute Inc., Cary, NC, USA). We calculated means and standard deviations (continuous variables) and percentages (categorical variables) of individual-level and neighborhood-level variables. For each neighborhood-level exposure, we ran separate main effect models predicting sleep outcomes. All models included age, gender, education, marital/cohabitation status, household annual income, presence of children in the home, length of residence in neighborhood, BMI, psychological distress, and neighborhood indicator (Hill District versus Homewood) as covariates. To assess whether associations between neighborhood-level exposures and sleep differed by neighborhood, we tested interactions between an indicator of neighborhood and each neighborhood-level exposure. We also conducted secondary analyses using multinomial logistic regression models to examine the association between neighborhood characteristics and the categorical definition of sleep duration. Also, we ran sensitivity analyses by excluding the small number of non-Black/African American participants. As results were virtually the same with and without the Black/African American participants, only models from the full sample (including non-black/non-African American participants) are presented herein.

Results

Sample characteristics

Descriptive statistics stratified by neighborhood and for the full sample are presented in Table 1. By design, 68 per cent ($N = 535$) of the sample was from the Hill District (intervention neighborhood), and the remaining 32 per cent ($N = 253$) resided in the Homewood neighborhood (Table 1). Women constituted 77 per cent of the sample. Annual household incomes averaged $20 900. Approximately 20.9 per cent of the sample was married or cohabiting, and 27.8 per cent of participants had children in the home. Participants were 55.2 years old on average, with an average BMI of 31.1 kg/m^2. Sleep efficiency averaged 80.9 per cent. WASO averaged 77.5 min. Total sleep time averaged 6.0 hr. There were no differences between the two neighborhoods in individual-level sociodemographic characteristics, psychological distress, BMI, sleep duration (continuous or categorical), social cohesion, or crime levels. However, there were significant neighborhood differences in length of residence in neighborhood, sleep efficiency, WASO, neighborhood safety, satisfaction, disorder, street lighting and walkability. Therefore, all models included the neighborhood indicator*neighborhood characteristic interaction term.

Neighborhood characteristics and sleep efficiency

In regression analyses (Table 2), higher levels of perceived neighborhood safety were associated with greater sleep efficiency ($B = 1.14$, $p < 0.05$). None of the other perceived neighborhood characteristics were associated with sleep efficiency, nor were there any significant interactions with neighborhood.

In terms of objective neighborhood characteristics, higher crime rates were associated with lower sleep efficiency ($B = -0.06$, $p < 0.01$). There was also a significant neighborhood*crime interaction for sleep efficiency ($B = 0.09$, $p < 0.05$). As shown in Figure 1, the association of crime with sleep efficiency was only evident in the Hill District. There were no other significant main effects of objective neighborhood characteristics on sleep efficiency; however, there was a significant cross-over interaction between neighborhood and walkability, indicating differential (though both non-significant) associations between walkability and sleep efficiency according to neighborhood.

Neighborhood characteristics and WASO

Similar to the sleep efficiency results, greater perceived neighborhood safety was associated with shorter WASO ($B = -5.64$, $p < 0.05$); however, none of the other perceived neighborhood measures were associated with WASO (Table 2). As with sleep efficiency, there was a significant neighborhood*crime interaction for WASO ($B = -0.40$, $p < 0.05$) such that the association of

Table 1. Study characteristics for the total analytical sample and stratified by neighborhood

	Mean (*SD*) or per cent		
	Total (*n* = 788)	Intervention neighborhood (*n* = 535)	Control neighborhood (*n* = 253)
Female	77.0%	78.1%	74.7%
Mean age (years)	55.2 (16.3)	55.3 (16.5)	55.2 (15.9)
Education			
Less than high school	13.3%	14.0%	11.9%
High school	42.8%	42.8%	42.7%
Some college	30.3%	30.7%	29.6%
College	13.6%	12.5%	15.8%
Annual household income in US$1000s	20.9 (19.2)	21.2 (19.4)	20.2 (19.0)
Married or living with partner	20.9%	19.6%	23.7%
Household with children	27.8%	26.5%	30.4%
Mean no. of years lived in neighborhood***	31.6 (23.0)	35.4 (23.6)	23.7 (19.5)
Psychological distress	4.3 (4.6)	4.2 (4.5)	4.6 (4.8)
Mean BMI (kg/m^2)	31.1 (7.4)	30.8 (7.2)	31.8 (8.0)
Mean minutes sleep duration	361.1 (84.8)	363.8 (84.1)	355.5 (86.2)
Mean sleep efficiency(%)**	80.9 (9.6)	81.7 (8.8)	79.2 (11.1)
Mean minutes of WASO*	77.5 (43.0)	74.9 (40.6)	83.0 (47.2)
Subjective neighborhood measures			
Social cohesion	3.1 (0.8)	3.1 (0.8)	3.0 (0.8)
Neighborhood safety***	2.9 (0.8)	3.0 (0.8)	2.6 (0.7)
Neighborhood satisfaction***	3.4 (1.2)	3.6 (1.1)	3.1 (1.2)
Objective neighborhood measures†			
Neighborhood disorder***	4.7 (0.9)	4.3 (0.7)	5.4 (0.7)
Street Lighting (% of street segments)***	97.1 (5.0)	97.6 (3.0)	96.1 (7.6)
Walkability index***	8.1 (1.7)	8.3 (1.8)	7.6 (1.5)
Pittsburgh Police Dept. Data‡			
Total crime	22.5 (18.9)	21.7 (19.6)	24.2 (17.4)

$^{*}p \leq 0.05$; $^{**}p \leq 0.001$; $^{***}p \leq 0.0001$.
†Sample sizes for the street segment audit data are total, $n = 723$; Hill District, $n = 486$; and Homewood, $n = 237$.
‡Sample sizes for crime data are total, $n = 775$; Hill District, $n = 525$; and Homewood, $n = 250$.

Table 2. Results of linear regression models predicting sleep duration, efficiency, and WASO from subjective and objective neighborhood characteristics

	Sleep efficiency (%)		Wakefulness after sleep onset (min)	Total sleep time (min)
	n	B (*SE*)	B (*SE*)	B (*SE*)
Perceived neighborhood characteristics				
Social cohesion	783	0.61 (0.54)	−2.10 (2.44)	7.58 (4.83)
Social cohesion*neighborhood	783	−0.82 (0.88)	4.91 (3.98)	−1.09 (7.87)
Safety	788	**1.14 (0.55)***	**−5.64 (2.47)***	2.26 (4.94)
Safety*neighborhood	788	−0.86 (0.98)	4.43 (4.39)	−10.46 (8.79)
Satisfaction	788	0.49 (0.37)	−2.09 (1.64)	1.53 (3.28)
Satisfaction*neighborhood	788	−0.45 (0.62)	2.46 (2.76)	2.23 (5.52)
Objective neighborhood characteristics				
Disorder	723	**−0.08 (0.59)**	1.45 (2.61)	0.05 (5.29)
Disorder*neighborhood	723	−1.56 (1.08)	8.95 (4.84)$^{\#}$	1.11 (9.79)
Street lighting	723	**1.96 (14.32)**	**7.23 (64.09)**	135.06 (128.89)
Street lighting*neighborhood	723	5.83 (16.44)	−31.21 (73.58)	−50.35 (147.97)
Walkability	723	0.37 (0.25)	−1.42 (1.11)	3.80 (2.24)$^{\#}$
Walkability*neighborhood	723	−0.95 (0.48)*	3.43 (2.14)	−7.76 (4.30)$^{\#}$
Pittsburgh Police Dept. Data				
Total crime	775	**−0.06 (0.02)****	**0.23 (0.10)***	−0.26 (0.19)
Crime*neighborhood	775	**0.10 (0.04)***	**−0.40 (0.18)***	0.36 (0.36)

Each of the neighborhood characteristics is entered into separate models. Each model includes the following covariates: neighborhood, age, male, married, income, education, any children in home, years lived in neighborhood, psychological distress, and BMI. For each model, the neighborhood interactions reflect the values for the control neighborhood. The intervention neighborhood is the reference category. Bold values indicate statistically significant results.
$^{**}p < 0.01$; $^{*}p \leq 0.05$; $^{\#}p < 0.10$.

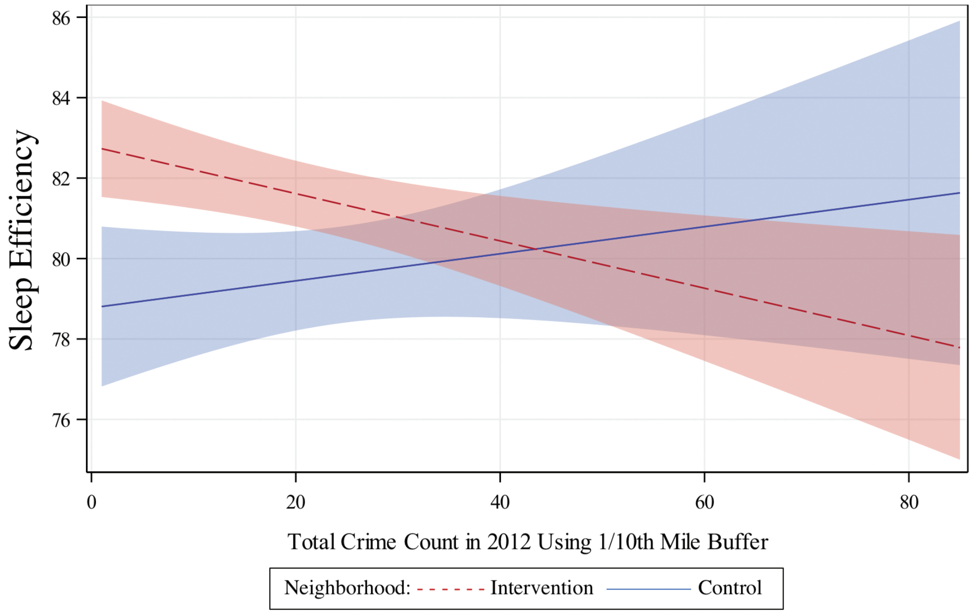

Figure 1. Predicted values for sleep efficiency according to total crime counts for each neighborhood.

crime with WASO was only evident in the intervention neighborhood (i.e. Hill District; Figure 2). There was also a marginal interaction between neighborhood disorder and neighborhood, such that greater disorder was associated with greater WASO, but only in the comparison neighborhood.

Neighborhood characteristics and sleep duration

As shown in Table 2, there was a marginal main effect of walkability and a marginal interaction between walkability and neighborhood on sleep duration, suggesting a positive association between more walkable neighborhoods and longer sleep duration, but only in the intervention neighborhood. None of the other perceived and objective neighborhood characteristics included in these analyses were significantly associated with either the continuous or categorical measure of sleep duration.

Discussion

The current findings are among the first to examine the association between perceived and objective indicators of neighborhood conditions and objectively measured sleep efficiency, WASO, and duration in a large, urban sample of predominantly African American residents from two socioeconomically disadvantaged neighborhoods. Results demonstrated significant, cross-sectional associations between greater objectively measured crime and poorer sleep efficiency and longer WASO. Notably, however, and consistent with other studies of neighborhood effects, the magnitude of these effects was small. In addition, there was a significant interaction between neighborhood indicator and crime such that the association between crime and sleep efficiency or WASO was only evident in the Hill District (the intervention neighborhood), despite that the two communities did not differ in crime levels at baseline. There was also a significant interaction between walkability and neighborhood on sleep efficiency, as well as marginally significant interactions between neighborhood and walkability for sleep duration, and neighborhood and disorder for WASO, suggesting a different pattern of associations between the two neighborhoods. With the exception of neighborhood disorder, findings were generally stronger and consistent with hypothesized associations in the intervention neighborhood (i.e., the Hill District). Importantly, this ongoing study is designed as a natural experiment to examine how changes in neighborhood conditions, spurred by considerable economic investment, primarily in the Hill District and to a much lesser extent in Homewood, will relate to changes in sleep and other downstream health consequences. It is not clear why the association between crime and sleep efficiency and WASO was not evident in Homewood, though it may be due to unmeasured neighborhood conditions that differentiate the neighborhoods (e.g. differences in media coverage of crime) and/or limited power due to the smaller sample in Homewood. Alternatively, one might speculate that Hill District residents were more sensitive to the effects of crime on their sleep because they had higher levels of perceived safety when compared with Homewood residents.

With regard to sleep duration, other than the marginally significant interaction between walkability and neighborhood, we did not find any other significant associations between other neighborhood characteristics and the continuous or categorical measure of sleep duration. The lack of significant associations between neighborhood conditions and sleep duration is generally consistent with the extant literature, as prior studies have similarly reported null results for actigraphy-assessed sleep duration [15, 17, 59], although there are exceptions [19]. Discrepancies across studies may reflect differences in the sample characteristics as well as differences in how neighborhood characteristics were evaluated. Importantly, indicators of disrupted sleep continuity (e.g. poorer efficiency and longer WASO), as well as short and long sleep duration are robustly linked with health outcomes, including cardiovascular disease morbidity and mortality [60, 61]. Some caution is warranted in interpretation of the multinomial regression results presented

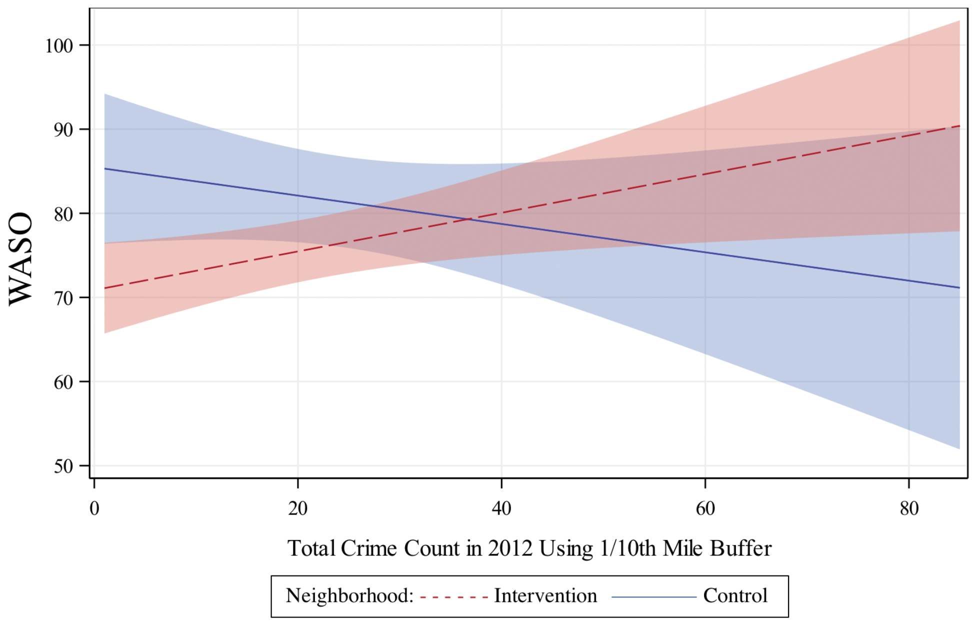

Figure 2. Predicted values for WASO according to total crime counts for each neighborhood.

herein, as only 3 per cent of the sample was categorized as long sleepers (>9 hr of sleep, on average). Thus, we were limited in our ability to investigate the degree to which neighborhood conditions associate with longer than normal sleep durations, and the small sample size may also have limited the power to detect statistical significance and precision of point estimates in the multinomial regression models.

Consistent with prior work [18, 19, 52], including our own previous publication in this sample which focused on subjective sleep quality [62], we found that greater perceived safety was associated with better sleep efficiency and shorter WASO, even after adjusting for sociodemographic characteristics, BMI, and psychological distress. We did not, however, find significant associations between other perceived neighborhood measures including social cohesion or neighborhood satisfaction and any of the sleep outcomes, after adjustment for covariates. This is in contrast to prior work, which has generally found associations between perceived neighborhood measures and subjective sleep outcomes. Importantly, by utilizing perceived and objective indicators of neighborhood conditions and objective measures of sleep, the current study overcomes potential biases including common method variance and negative affect bias that may be inherent in the prior literature which has predominantly focused on self-reported neighborhood conditions and sleep. Finally, the overall small magnitude of the effects of neighborhood conditions on sleep both within our study and across studies may contribute to inconsistencies.

Given these findings, it is important to consider the potential pathways that may account for the observed associations. Our findings are consistent with research and theory suggesting that a sense of environmental safety and security should contribute to better sleep, at least in part, by reducing physiological and negative emotional arousal, which are antithetical to sleep [12, 13, 63]. Importantly, the fact that findings persisted even after adjustment for psychological distress suggests that the association between neighborhood disadvantage and disrupted sleep continuity is not exclusively due to psychological distress. We also found that aspects of the physical environment, namely, walkability and disorder were associated sleep outcomes, but effects were dependent on the neighborhood (as indicated by interaction terms). We did not find significant associations between street lighting and sleep outcomes; however, this may be due in part, to the limited variability in this measure, derived from street segment audits. Nevertheless, it is important for future work to examine aspects of the physical and social environment in relation to sleep, as there may be competing pathways that differentiate the effects of a given characteristic on sleep. For instance, from a social environment perspective, one might hypothesize that greater exposure to street lighting could enhance feelings of safety and security, thereby improving sleep. However, from a physical environment perspective, exposure to street lighting may disrupt sleep continuity and duration, potentially contributing to circadian disruption or perhaps in areas with greater lighting, residents are more likely to stay out at night. There are several other direct pathways through which neighborhood conditions may influence sleep, including direct effects via noise or other environmental pollutants; however, the study did not measure these constructs.

These findings must be interpreted within the context of several study limitations. First, because the data are cross-sectional, we cannot infer causality. We hope to address this limitation in the context of our ongoing study which will examine how changes in neighborhood conditions associate with changes in sleep. Second, although we statistically adjusted for many potential confounders of the association, including individual-level sociodemographic characteristics, psychological distress, and BMI, we did not control for other key confounders, particularly sleep disorders such as sleep apnea. Given that the sample is comprised of predominantly African American, overweight women, a population at high risk for sleep apnea [64], such an explanation is plausible. Although we controlled for BMI which is a robust risk factor for apnea, associations between neighborhood conditions and sleep outcomes may be due to the confounding of sleep apnea or some other unmeasured variable(s). As mentioned, although we included a number of potentially relevant objective neighborhood measures, we did not include others that may be particularly salient for sleep, including environmental pollutants and noise levels [31]. Finally, although the use of actigraphy is a strength of our study relative to sole reliance on self-reported assessments of sleep, actigraphy also has limitations and provides an imperfect, albeit validated, behavioral measure of sleep. Furthermore, we did not distinguish between weekday and weekend sleep patterns, which may have introduced heterogeneity; however, such distinctions are somewhat arbitrary in a population with nonstandard work hours and/or not working. Finally, residential selection into neighborhoods could bias results, as unobserved characteristics (e.g. health consciousness) may underlie an individual's residential location and may also influence their sleep.

These limitations notwithstanding our study makes several unique contributions to the literature, including the inclusion of a variety of perceived and objective neighborhood conditions, as well as key objectively determined dimensions of sleep (duration, efficiency, and WASO) that are linked with morbidity and mortality. Finally, our study makes an important contribution to the literature and is relevant to public policy, as we address these questions in a high-risk and understudied population of urban, African American residents living in socioeconomically disadvantaged neighborhoods.

Neighborhood disadvantage is an important social determinant of health and health disparities, including sleep health. African Americans are disproportionately more likely to live in disadvantaged neighborhoods, even after accounting for individual-level socioeconomic status and are at increased risk for a number of sleep problems and disorders, including short sleep duration, poor sleep efficiency and quality, and increased risk for sleep apnea. Public health professionals and policy makers may consider neighborhood disorder, exposure to street lighting, crime levels, and perception of safety as key, modifiable, neighborhood factors that could contribute to the disproportionate burden of poor sleep health among African Americans and those living in socioeconomically disadvantaged neighborhoods.

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