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The Role of the Physical Environment in Racial Differences in Sleep Duration

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Abstract

The Role Physical Environment in Racial Differences in Sleep Duration
By Krysta Medearis

Background: Racial minorities are more likely to have shorter sleep duration; however, the mechanism is unclear. Recent studies have found that the neighborhood environment is associated with sleep duration. Thus, the neighborhood environment may explain racial sleep disparities. This study examined the role of the physical environment in racial differences in sleep duration among men and women (N=2020) in the Multi-Ethnic Study of Atherosclerosis.

Methods: Participants underwent 1-week actigraphy, completed questionnaires on the neighborhood environment, and addresses were geocoded and linked to physical environment features. Actigraphy-measured sleep duration was analyzed as both continuously and categorically (short sleep duration < 6 hours vs. ≥ 6 hours). Physical environment characteristics included availability of healthy foods, aesthetic quality, walking environment, walking destination density, the proportion of land dedicated to retail space and the overall built environment. Multi-level linear and Poisson regression models with robust variance were fit to examine the associations of race, the physical environment, and sleep duration with adjustment for covariates.

Results: The mean age was 68.5 ± 9.1 years. Approximately 46% of participants were male and 37.8% White, 26.9% Black, 21.9% Hispanic, and 11.3% Chinese American. There was a high prevalence of short sleep duration, 31% slept < 6 hours and 62.8% slept <7 hours. The prevalence of short sleep (<6 hours) was highest for racial minorities, ranging from 32.2% to 44.3% compared to 19.2% for White adults. Hispanic individuals were more likely to live in areas with lower aesthetic quality and in areas with a higher walking destination density. Chinese individuals were more likely to live in areas with a lower score for walking environment and a low built environment factor score. Black participants were more likely to reside in areas with less availability of healthy food. A standard deviation increase in neighborhood aesthetic quality was associated with sleeping 4.5 minutes longer on average, (β=4.5, 95% CI: 0.9, 8.0). Whereas individuals living in areas with more walking destinations (β=-8.1, 95% CI: -11.6, -4.7), a higher proportion of land dedicated to retail space (β=-6.5, 95% CI: -9.9, -3.0), and a higher built environment factor score (β=-8.8, 95% CI: -12.3, -5,3) had a shorter sleep duration. The physical environment partially explained some of the racial disparities in sleep duration between Hispanic or Chinese (but not Black) and White adults. The Hispanic-White difference in sleep duration was attenuated from 10.4 minutes (95% CI: -20.1, -0.7) to 9.5 minutes (95% CI: -19.2, 0.3) with adjustment for aesthetic quality. The Hispanic-White difference was further attenuated to 6.7 minutes (95% CI: -16.5, 3.1), 9.0 minutes (95% CI: -18.7, 0.8), and 4.8 minutes (95% CI: -14.7, 5.1) with adjustment for walking destination density, proportion of land dedicated to retail space, and the built environment factor score, respectively. The Chinese-White difference in sleep duration was attenuated from 31.4 minutes (95% CI: -43.5, -19.3) to 29.0 minutes (95% CI: -41.2, -16.9) with adjustment for proportion of land dedicated to retail space.

Conclusion: Black, Hispanic, and Chinese individuals had shorter sleep duration than White individuals. Physical environment features explained some of the Hispanic and Chinese-White differences in sleep duration. This study provides support that the physical environment may be an important mechanism in which racial disparities in sleep exist and is a likely a point of intervention.

The Role Physical Environment in Racial Differences in Sleep Duration

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INTRODUCTION

Sleep

Sleep plays a critical role in maintaining mental and physical well-being.[1] Sleep is defined as a natural and reversible state of reduced responsiveness to external stimuli and relative inactivity, accompanied by a loss of consciousness.[2] Sleep occurs in regular intervals and is homeostatically regulated by a circadian process. This circadian process is a clocklike mechanism that determines the alteration of periods with high and low propensity, and an ultradian process occurring within the sleep episode in two basic sleep states, non-rapid eye movement (non-REM) sleep and rapid eye movement (REM) sleep.[3]

A typical person will cycle through 3 different stages of non-REM and REM sleep several times in a typical sleep cycle.[4,5] Following a period of wakefulness, the sleep period includes non-REM (N1, N2, N3) and REM.[5] As the night progresses, fewer non-REM stages occur, and the duration of REM sleep increases.[6] During open-eye wakefulness, alpha and beta waves are present, however beta waves are predominant. As a person becomes drowsy, the eyes close and the alpha rhythm becomes the predominant pattern.[5] Next, the person enters N1 sleep. N1 is the lightest stage of sleep and occurs when more than 50% of alpha waves are replaced with low-amplitude mixed-frequency (LAMF) activity. Breathing tends to occur at a regular rate, and this stage typically lasting 1 to 5 minutes. Consisting of 50% of the total sleep, N2 represents a deeper sleep and lasts for about 25 minutes. During this stage, the heart rate and body temperature drop. N3 is considered the deepest stage of sleep and is characterized by a much slower frequency with high amplitude signals known as delta waves. During this stage the body repairs and regrows its tissues, builds bone and muscle, and strengthens the immune system. During the final stage of sleep, REM, an individual's breathing rate becomes erratic and irregular. It is hypothesized that REM sleep contributes to memory consolidation, a process in which a temporary labile memory is transformed into a more stable long-lasting form.[2,7] Evidence suggests that dreaming is also influenced by the consolidation of memory during sleep.[8] REM sleep stages typically lasts 10 minutes.[9] Within each stage, sleep is also divided into sequential 30-second epochs.[5] Each stage of sleep serves an important purpose in keeping the mind and body healthy.

Sleep plays a vital role in brain function and systemic physiology, including metabolism, appetite regulation, and the functioning of immune, hormonal, and cardiovascular systems.[1] The American Academy of Sleep Medicine and the Sleep Research Society recommends that adults sleep greater than 7 hours per night to promote optimal health.[10] Despite the importance of healthy sleep duration, 35% of adults report a short sleep duration (<7 hours).[11] A short sleep duration is associated with obesity, diabetes, hypertension, heart disease, and stroke.[12] Numerous studies have documented racial disparities across these conditions.[13–17] It is hypothesized that sleep may be a contributing factor in these racial health disparities.

Racial Disparities in Sleep

Critically, sleep disruption is common in the United States (US), particularly among racial minorities.[18–23] Recent studies and meta-analysis have found that Black Americans are more likely to experience: poorer sleep continuity and quality, excessively short or long sleep duration, greater sleep variability, and are at greater risk for sleep apnea.[22,24,25] A study of racial differences in sleep disturbances found that middle-aged Hispanic and Chinese individuals had higher odds of short sleep and higher prevalence of moderate or severe sleep breathing disorder (SBD) than White individuals.[21] In the previous study, authors also found that the shortest sleep duration was observed among Black men, who on slept on average 75 minutes less than White women.[21] Similarly, in the Chicago Area Sleep Study (CASS), Carnethon and colleagues found that Asian participants had shorter mean sleep duration compared to White participants.[26] However it is important to note that while Asian adults had shorter sleep durations compared to White adults, the sleep durations were longer than those for Black participants but less than Hispanic participants.[26] Collectively, these studies demonstrate that racial and ethnic minorities in the United States experience worse sleep outcomes compared to their White counterparts. Notably, studies suggest that Black individuals bear a disproportionate burden among racial minorities. As a burgeoning body of research demonstrates, it is imperative for public health to study the determinants of racial disparities in sleep.

Neighborhood and Health

Numerous studies have shown that the neighborhood environment is a determinant of health.[27–30] Research suggests that neighborhoods have an impact on health outcomes that is beyond individual-level behaviors of residents.[31] Neighborhood can be defined in multiple ways. Researchers commonly characterize the neighborhood by participant self-report of neighborhood conditions.[32,33] Despite the potential limitations of reporting bias and same source bias, studies suggest that self-reported neighborhood characteristics can be reliably measured.[32,34] More broadly, neighborhood environment is comprised of social and physical characteristics. The social environment encompasses features such as safety, crime, and cohesion, while the physical environment typically includes aspects of the built environment, the natural environment, and the ambient environment.[35] Additional features of the physical neighborhood environment include land use density, street connectivity and recreational resources.[27] Neighborhoods are also characterized by noise levels, air pollution and ambient light.[36–38] Emerging evidence demonstrates that elements of the social and physical neighborhood environments are associated with sleep outcomes.

Neighborhood environment and sleep

The neighborhood social and physical environment can affect an individual's sleep patterns.[39,40] Recent analyses of nationally-representative surveys of the United States and Australia have shown that various aspects of the environment, including green spaces and natural water were associated with the likelihood of reporting insufficient sleep.[39,40] A study investigating the relationship between neighborhood walking environment and obstructed sleep apnea (OSA), found that people in the least walkable areas had a greater severity of OSA.[41] Among a geographically diverse-middle-aged sample, higher neighborhood walkability was associated with shorter average sleep duration, however this association was partially explained by noise.[42] A study assessing factors contributing to sleep outcomes found that airplane, roadway, and rail noise pollution; air pollution from ozone and particulate matter; and to some extent, ambient light interfered with a person's ability to fall asleep, stay asleep, and wake feeling rested.[43] In a separate study, living in an adverse neighborhood social and physical environment, and in an area of lower neighborhood SES were associated with greater sleepiness, however the associations were attenuated after adjusting for sociodemographic characteristics.[44] This body of evidence supports that the neighborhood environment is an important determinant of sleep health.

Race, environment, and sleep

A limited body of research has found that the environment may be a salient risk factor for sleep disturbances among historically minoritized racial and ethnic groups.[30,39,43–46]
Black adults, in particular, are significantly more likely to live in disadvantaged

neighborhoods with limited access to healthcare and greater exposure to noise and congestion.[47] A study of Black-White differences in the association between housing type and sleep duration found that Black men and women who lived in a house/apartment were more likely to be short sleepers than their White counterparts.[45] Billings and colleagues demonstrated that the neighborhood walking environment was associated with sleep apnea severity, particularly among Black individuals.[41] Among a sample of 820 Black adults from socioeconomically disadvantaged neighborhoods, Holliday and colleagues found that perceived infrastructure was significantly associated with lower sleep efficiency.[48] Similarly, among a study of Hispanic adults living in the US, Simonelli and colleagues found a higher prevalence of short sleep and insomnia in those living in an adverse neighborhood environment.[30] These studies highlight the importance of investigating the association of the environment on racial disparities in sleep.

Neighborhood as a Contributor to Racial Disparities in Sleep

Evidence suggests that the neighborhood environment may contribute to racial disparities in sleep. For example, among participants of the Childhood Adenotonsillectomy Trial, Black children were 12.8 times more likely to live in a distressed neighborhood and 1.33 times more likely to have a higher Apnea-Hypopnea Index (AHI).[49] In the prior study, poverty rate and percentage of single-female-headed households, characteristics of the neighborhood environment explained 34% and 55%, respectively, of the racial difference in AHI, a measure of OSA.[49] In examining other aspects of the environment, a study found that neighborhood safety in childhood mediated 10% (3.70 min) of the racial difference in sleep duration.[23] Similar data among adults are limited. In a notable exception, a sample of 133 African American and 223 European American adults, found that neighborhood disadvantage explained 24% of the racial difference in wakefulness after sleep onset.[18] These prior studies support that the environment may mediate racial disparities in sleep. It is important to identify the specific dimensions of the environment, such as availability of healthy foods, aesthetic quality, walking environment, walking destination density and proportion of land dedicated to retail, that may play a role in racial disparities in sleep to better target intervention.

The primary aim of this study was to examine the role of the physical environment in racial disparities in sleep duration among a multi-ethnic sample of adults between 45 and 84 years old. We hypothesized that physical environment, measured by the availability of healthy food, aesthetic quality, walking environment, walking destination density, and proportion of land dedicated to retail space, will partially explain racial disparities in sleep duration.

METHODS

Participants

The current study utilizes data from the Multi-Ethnic Study of Atherosclerosis (MESA), an ongoing multicenter cohort study of 6 US communities in Maryland, Illinois, North Carolina, California, New York, and Minnesota. The study was initiated in July 2000 to investigate the prevalence, correlates, and progression of subclinical cardiovascular disease (CVD).[50] Between July 2000 and August 2002, 6814 participants (3601 women; age range, 45-84 years) were recruited for the study. Participants defined themselves as White (38.5%), African American (27.8%), Hispanic (21.9%), or Chinese American (11.8%). Between 2000 and 2012, 5 examinations were conducted. The current analysis uses data from the Neighborhood Ancillary Study (2010 – 2012, n = 6191), the Sleep Ancillary Study (2010 – 2013, n = 2261), and covariates from examination 5 (2010-2013). The Neighborhood Ancillary Study was designed to characterize the neighborhood environment and examine the associations of specific features of the neighborhood environment with health.[51] The MESA Sleep Study was developed to understand how variations in sleep and sleep disorders vary across gender and relate to subclinical atherosclerosis.[21,52] Institutional Review Board approval was obtained at each study site and written informed consent was obtained from all participants.

Measures

Physical Environment

The physical environment was characterized as aesthetic quality, access to healthy food, walking environment, walking destination density, and proportion of land dedicated to retail. Survey-based measures of neighborhood characteristics were administered to MESA participants in Exam 5 (2010 to 2013, n = 4077) as part of the MESA Neighborhood Ancillary study. Participants were asked to refer to the area of about one mile around their home when responding to a series of questions. Three elements of the physical environment were assessed using survey scales. Aesthetic quality was measured with the following 3 items: "There is a lot of trash and litter on the street in my neighborhood", "There is a lot of noise in my neighborhood", and "My neighborhood is attractive". Walking environment was assessed using the following 4 items: "It is pleasant to walk in my neighborhood", "In my neighborhood it is easy to walk to places", "I often see other people walking in my neighborhood", and "I often see other people exercise in my neighborhood". Lastly, availability of healthy foods was assessed with the following 2 items: "A large selection of fresh fruit and vegetables is available in my neighborhood" and "A large selection of low fat foods is available in my neighborhood".[53] All survey scales used a 5-point Likert scale with response options from 'strongly agree' to 'strongly disagree'. Questions were reverse coded when needed so that higher scores indicate a more favorable environment. Summary scores ranged from 1 to 5 and were not calculated for participants who did not answer one or more of the questions within a scale. Scores for each dimension were then averaged for each question for an overall score of the physical environment.

Measures of walking destination density, and proportion of land dedicated to zoned retail (proportion retail), were previously developed in the MESA Neighborhood Study, using ½ mile and 1 mile buffers.[28,54] Participants addresses were geocoded as a part of the Neighborhood Ancillary Study. Walking destination density was measured as the number of popular walking destinations within ½ mile of the participant's home. Walking destinations were identified using Standard Industrial Classification Codes and data obtained from the National Establishment Time Series Database.[55,56] Between 2001 and 2005 land-use data were collected from all six study sites. An investigator classified land-use codes into four mutually exclusive categories: retail, residential, industrial, and office. Availability of retail in each neighborhood was calculated using the percentage of land area in parcels that contain retail spaces within one mile of a participant's geocoded address.

A built environment factor score was calculated using walking destination density, percentage of land dedicated to residential space, and population density, by multiplying the factor weights by the standardized variables and summing for variables loading at 0.8 or higher on that factor. Built environment metrics may be interrelated and highly collinear, thus principal component analysis was used to identify their underlying factors and compute composite scores. A composite score was created for each factor based on the weighted sum of the standardized items with heavy loading (>0.5) for that factor.

Sleep measures

Between 2010 and 2013 participant sleep patterns were assessed via 7-day wrist actigraphy as part of the MESA Sleep Ancillary Study (n = 2261). Participants wore the

Actiwatch Spectrum device (Philips Respironics, Murrysville, Pennsylvania) on their nondominant wrists for 7 consecutive days, while completing a sleep diary.[57] Sleep onset was defined as 5 immobile minutes, and sleep offset was defined as 0 immobile minutes and a wake threshold of 40 counts. We examined sleep duration as the sum of all epochs scored as sleep in the main sleep period, measured in minutes. Short sleep duration was defined as < 6 hours with a referent group of ≥ 6 hours. Approximately 2% of participants were long sleepers (≥9 hours). Due to the small sample size, long sleepers were grouped with the referent group. Sleep duration was transformed into minutes for analysis.

Covariates

Sociodemographic variables

The following variables were included as covariates: Self-reported race (White, Black, Hispanic, or Chinese), age (in years), gender (male or female), education, household income, employment status, marital status, BMI, and CES-D. Education was categorized as less than high school graduate, high school graduate, some college, and college degree or higher. Household income was divided in 15 categories ranging from <$5000 to >$150000. For study sample demographics only, we further categorized income into 4 groups (< $25000, $25000 – $49000, $50000 – $74000, and ≥ $75000). Employment status was categorized as working at least part-time or not (including employed on leave, unemployed, and retired). Marital status was dichotomized as “currently married or living with partner” or “other” (including widowed, divorced, separated, and never married).

Body Mass Index (BMI)

Measured weight and height were used to calculate BMI, and categorized as follows: <25, 25–29.9, and ≥ 30 kg/m^2, to represent normal, overweight, and obese individuals for all analyses.[58] BMI was analyzed continuously in our regression models.

Center for Epidemiologic Studies Depression scale (CES-D) Depressive symptoms at Exam 5 were measured with the CES-D, which is a 20-item self-report questionnaire that asks respondents to rate how often in the past-week they have experienced depressive symptoms on a four-point scale (0–3). The sleep measure was removed, and the CES-D scores were rescored excluding the sleep item. Higher scores indicate a higher symptom severity.

Statistical Analysis

Of the 6814 MESA participants, 4716 completed the exam 5 follow up. Sleep data were available for 2151 participants. Of these, 131 were missing at least 5 days of sleep data or neighborhood variables, yielding a final sample size of 2020. Descriptive statistics were examined by race, and tested using independent-samples t-tests, for continuous measures, or chi-squared tests, for categorical measures.

Intraclass correlation coefficients (ICC) were calculated to measure clustering at the neighborhood level (Appendix Table 1). The ICC was calculated as the ratio of the variance between neighborhoods divided by the sum of between neighborhood components. ICCs were computed by modeling the outcome, sleep duration, with and without each physical environment measure for comparison. The ICC ranges from 0 to 1, with a higher value indicating clustering within neighborhoods. Pearson's correlation test was used to determine the correlation between physical environment measures. Independent t-tests were used to determine differences in the distribution of the neighborhood environment scores by race.

Multi-level linear regression models were fit to assess the associations between the physical environment and continuous sleep duration. Additionally, multi-level Poisson regression models with robust variance were fit to estimate prevalence ratios (PRs) and 95% confidence intervals (CIs) for categorical sleep duration with physical environment measures. Physical environment characteristics were modeled as continuous variables, standardized to a mean of 0 and standard deviation (SD) of 1 to facilitate comparisons. We used a sequential modeling approach as follows: Model 1 adjusted for age and gender, and Model 2 further adjusted for education, household income, employment, marital status, BMI, and CES-D.

To understand the role of the physical environment on racial disparities in sleep duration, the models were further adjusted for availability of healthy food (Model 3), aesthetic quality (Model 3), walking environment (Model 4), walking destination density (Model 6), proportion retail (Model 7), and an overall measure of the physical environment referred to as the built environment factor score (Model 8).

RESULTS

Sample descriptive statistics by race are shown in Table 1. The mean age was 68.5 $\pm$ 9.1 years. Approximately 46% of participants were male and 37.8% self-identified as White, 26.9% as Black, 21.9% as Hispanic, and 11.3% as Chinese American. Over one-third of participants received a bachelor's degree (38.1%). Nearly two-thirds of participants were married (59.8%) and nearly half were employed (48.2%). The mean BMI was highest among Black (30.5 kg/m^2, SD = 5.6), and Hispanic (30.2 kg/m^2, SD = 5.4) individuals and was the lowest among Chinese (24.3 kg/m^2, SD = 3.4) individuals. Hispanic individuals (8.86, SD = 8.1) had the highest depression scores while Chinese individuals (6.18, SD = 5.7) had the lowest.

Overall, participants slept 6.49 hours (SD = 1.35) on average. About a third of participants slept less than 6 hours (31.1%) and almost two-thirds slept less than 7 hours (62.8%). The prevalence of short sleep (<6 hours) was highest among Black participants (44.3%) and lowest among White participants (19.2%) (Figure 1).

Black participants in comparison to their White counterparts were less likely to live in areas with healthy food available (3.95, SD = 0.99 for Black vs. 3.73, SD = 1.07 for White, Figure 2). Hispanic participants in comparison to their White counterparts were more likely to live in areas with low aesthetic quality (3.64, SD = 0.74 for Hispanic vs. 3.95, SD = 0.67 for White, Figure 3), dense walking destinations (123.6, SD = 131.9 for Hispanic vs. 74.5, SD = 125.9 for White, Figure 4) and areas with a higher proportion of land dedicated to retail space (0.06, SD = 0.03 for Hispanic vs. White 0.05, SD =0.04, Figure 5). Chinese participants in comparison to their White counterparts were more likely to live in areas with a higher proportion of land dedicated to retail space, (0.06, SD = 0.03 for Chinese vs. White 0.05, SD =0.04, Figure 5), a worse walking environment (3.91, SD = 0.60 for Chinese vs. 4.15, SD = 0.68 for White, Figure 6), and less built environment (-0.8, SD = 1.0 for Chinese vs. -0.1, SD = 2.1 for White, Figure 7).

Table 2 demonstrates correlations between the physical environment measures. There was a strong correlation between proportion retail and walking destination density (r = 0.6). All other correlations between physical environment measures were weak.

Appendix Table 1 demonstrates clustering among physical environment measures and sleep duration. ICCs for sleep duration decreased with inclusion of availability of healthy food, walking destination density, and the built environment factor score. In contrast, ICCs increased after adjusting for aesthetic quality and proportion of land dedicated to retail space. There was no change with the adjustment for walking environment.

Table 3 demonstrates the associations between physical environment characteristics (e.g., availability of healthy, aesthetic quality, walking environment, walking destination density, proportion retail, the built environment factor score) and sleep duration. A SD increase in the aesthetic quality of the physical environment was associated with sleeping 5.0 minutes (95% CI: 1.5, 8.5) longer on average after adjustment for age and sex. The association persisted in the fully adjusted model (β= 4.5 min, 95% CI: -0.9, -8.0). For a SD increase in walking destination density and proportion of retail space within one-mile surrounding area, individuals slept 5.2 minutes (95% CI: -8.8, -1.7) and 5.8 minutes (95% CI: -9.3, -2.2) less on average, respectively. The associations persisted in the fully adjusted models (β = -8.1 min, 95% CI: -11.6, -4.7) and (β= -6.5 min, 95% CI: -9.9, -3.0), respectively. Similarly, for a SD increase in the built environment factor score, a composite measure consisting of walking destination density, proportion retail, and population density, individuals slept 6.1 minutes (95% CI: -9.7, -2.6) less on average. The association persisted in the fully adjusted model (β = -8.8 min, 95% CI: -12.3, -5.3). Associations were similar with prevalence of short sleep duration. Individuals who resided in areas with better aesthetic quality had a lower prevalence of short sleep duration (Prevalence ratio (PR)= 0.87, 95% CI: 0.84, 0.94). The association persisted in the fully adjusted model. Furthermore, walking destination density, proportion of land dedicated to retail space in within a one-mile area, and the built environment factor score were associated with a higher prevalence of short sleep duration (PR = 1.11, 95% CI: 1.05, 1.17; PR: 1.11, 95% CI: 1.04, 1.17; PR = 1.05, 95% CI: 1.03, 1.08, respectively). The associations persisted in fully adjusted models.

Table 4 demonstrates the associations of race, the physical environment, and sleep duration with adjustment for covariates. Black-White differences in sleep duration persisted with adjustment for covariates and physical environment measures. However, the Hispanic-White difference in sleep duration was attenuated with adjustment for select physical environment measures. Hispanic individuals slept 17.2 minutes (95% CI: -26.1, -8.3) less than White participants, and after adjustment for socio-demographics, BMI, and depressive symptoms the difference was reduced to 10.4 minutes (95% CI: -20.1, -0.7). The Hispanic-White sleep duration difference was further attenuated with adjustment for aesthetic quality [β = -9.5 (-19.2, 0.3)], walking destination density [β = -6.7 (-16.5, 3.1)], proportion retail [β = -9.0 (-18.7, 0.8)] and the built environment score [β = -4.8 (-14.7, 5.1)]. Adjustment for availability of healthy foods and walking environment did not change the difference in sleep duration between Hispanic and White participants. The difference in sleep duration for Chinese and White individuals was attenuated with adjustment for the proportion of land dedicated to retail space [β = -29.0 (-41.2, -16.9)]. There was no change in the Chinese-White difference in sleep duration after adjustment for the availability of healthy food, aesthetic quality, walking environment, walking destination density, and the built environment factor score.

Table 5 shows prevalence ratios of race, the physical environment, and short sleep duration (<6 hours) with adjustment of covariates. Black-White differences in sleep duration persisted with adjustment for covariates and physical environment measures. Hispanic-White differences in sleep duration were similar to the findings for continuous sleep duration. Hispanic individuals had a higher prevalence of short sleep duration than White participants (PR: 1.68, 95% CI: 1.36, 2.07). After adjustment for socio-demographics, BMI, and depressive symptoms to the prevalence of short sleep duration comparing Hispanic to White participants was 1.48

(95% CI: 1.18, 1.84). The Hispanic-White difference in the prevalence of short sleep was further attenuated with adjustment for aesthetic quality [PR = 1.40 (1.13, 1.80)], walking destination density [PR = 1.40 (1.13, 1.74)], proportion retail [PR = 1.45 (1.67, 1.81)] and the built environment score [PR = 1.36 (1.09, 1.69)]. Adjustment for availability of healthy foods and walking environment did not change the difference in sleep duration between Hispanic and White participants. The difference in the prevalence of short sleep duration for Chinese and White individuals was attenuated from 2.04 (95% CI: 1.62, 2,58) to 1.97 (95% CI: 1.57, 2.49) with adjustment for the proportion of land dedicated to retail space. In general, there was no change in the prevalence of short sleep duration between Chinese and White participants with the adjustment for availability of healthy foods, aesthetic quality, walking environment, walking destination density and the built environment factor score.

DISCUSSION

This study examined the role of the physical environment in racial disparities in sleep duration among a diverse sample in the US. Features of the physical environment were associated with sleep duration. Specifically, aesthetic quality was associated with longer sleep duration and walking destination density, proportion retail, and the built environment factor score were associated with shorter sleep duration. There were racial disparities in sleep duration, with Black, Hispanic, and Chinese individuals having shorter sleep duration in comparison to White individuals. There was a reduction in the Hispanic-White difference in sleep duration with adjustment for aesthetic quality, walking destination density, proportion of land dedicated to retails space, and the built environment factor score. Also, the Chinese-White difference in sleep duration was reduced with adjustment for the proportion of land dedicated to retail space. However, it is important to interpret the prior finding with caution due to the wide confidence interval. There was no evidence that the physical environment explained the Black-White difference in sleep duration. The results of this paper suggest that the physical environment may be an important target for sleep health, and for the reduction of Hispanic-White disparities in sleep duration.

Features of the physical environment were patterned by race. We found that Hispanic participants were more likely to reside in areas with lower aesthetic quality scores and a higher walking destination density. Chinese participants were more likely to live in areas with a lower score for the walking environment and in less built environments. Black participants were more likely to reside in areas with less availability of healthy food. White and Black participants were more likely to live in areas with a lower proportion of retail. Several studies have shown that racial minorities are more likely to live in less favorable environments.[45,59–61] The patterning of historically minoritized groups in less desirable neighborhoods are the result of structural racism. There were discriminatory plans, policies, practices, and lack of investment in neighborhoods with a high proportion of racial minorities or those of lower SES.[62–64] One of the most notable practices is redlining, which refers to the 1930s era Home Owners' Loan Corporation (HOLC) process of generating neighborhood grades using a color-coded schema. The HOLC color-coded areas red if they included high populations of Black, immigrant, or working-class individuals.[65] Red areas were deemed as hazardous and risky for investment, preventing Black and immigrant individuals from accessing mortgage financing and homeownership.[66] This act of redlining has had a long-lasting effect on neighborhood makeups today and are associated with poor health outcomes,[67–70] and sleep as shown in the current study.

Similar to the patterning of the environmental features, Black, Hispanic, and Chinese participants had a shorter sleep duration than White participants. Our findings are consistent with the literature. For example, researchers using data from the Chicago Area Sleep Study (CASS), found that sleep duration was significantly shorter for Black, Hispanic, and Asian participants compared to White participants.[26] However, the mean sleep durations in CASS were longer than the sleep durations observed in the current study. In CASS, White, Black, Hispanic, and Asian participants slept 7.41 hours, 6.82 hours, 6.95 hours, and 6.88 hours, respectively compared to MESA participants who slept, 6.83 hours, 6.03 hours, 6.34 hours, and 6.54 hours, respectively. The shorter sleep duration observed in MESA may be attributable to the age – MESA participants were older than CASS participants. However, both studies as well as others demonstrate the need to identify the determinants of short sleep duration in these populations.

It has been documented that the environment is associated with sleep.[39,40] We found that aesthetic quality was associated with a longer sleep duration, while walking destination density, proportion of land dedicated to retail space, and the built environment factor score were associated with shorter sleep durations. Aesthetic quality is a measure that characterizes a person's environment by assessing the presence of trash, noise, and the attractiveness of one's environment. Research has shown that areas with neighborhood disorder, which includes a lower aesthetic quality have been associated with worse sleep outcomes.[71,72] Furthermore, a longitudinal study examining the impact of neighborhood development on sleep outcomes, found that people who live closer to a neighborhood that has been invested in slept longer than those who lived farther from neighborhood investments.[63] The investments mentioned in the previous study improved the aesthetic quality of the environment and walkability. However, we did not find that walking environment or other measures of the built environment were favorable for sleep duration. Although this finding was consistent with the literature suggesting the built environment negatively impacts sleep,[35,42,73] other studies have shown that built environment attributes are associated with better health outcomes including obesity, hypertension, and diabetes.[74–78] There are a few plausible reasons for the conflicting findings. In our study walking destination density represents the number of walking destinations within a ½ mile of a person's home, however walking destination density may not actually represent walking habits, which are associated with better sleep.[54,79,79] Neighborhoods with a higher walking destination density, proportion retail, and built environment score may have more noise and traffic.[42] In particular, areas with a higher walking destination density may have more social destinations, which have been shown to be associated with shorter sleep duration.[42] These environments may promote more noise. Evidence has shown that exposure to noise is associated with shorter sleep duration and sleep disorders such as insomnia.[37,80] Furthermore, we found that areas with a higher proportion of retail space were associated with a shorter sleep duration. Chum and colleagues found that commercial land use was associated with short sleep duration after adjusting for traffic and noise.[81] This supports the idea that environments with more retail space may have more traffic and noise. Participants who live near areas with more traffic are likely to be exposed to air pollution which has been associated with short sleep duration.[82–84] Our findings show that built environment features may promote activities and disturbances that disrupt sleep. Future studies should examine the pathway by which the built environment is negatively associated with poor sleep.

The physical environment played a role in racial disparities in sleep for Hispanic and White participants. Specially, Hispanic-White differences in sleep duration were attenuated with the adjustment of physical environment measures such as aesthetic quality, walking destination density, proportion of land dedicated to retail space, and an overall built environment factor score. Research has shown that Hispanic individuals disproportionately live in adverse neighborhoods with more noise.[30,85] In a study among Hispanic/Latino adults, Simonelli and colleagues found that nearly half of their participants reported violence or noise as neighborhood problems, which were associated with short sleep duration and insomnia.[30] Neighborhood features like noise, may be contributing to the Hispanic-White sleep disparity, which warrants more investigation. Moreover, Hispanic populations have a history of systemic barriers associated with immigrant status in the United States.[86,87] These barriers have shaped their environments and may contribute to adverse sleep outcomes. Research has shown that the socioeconomic status of Hispanic individuals is significantly lower than White individuals.[86] Furthermore, evidence supports that socioeconomically disadvantaged individuals are more likely to sleep in environments prone to noise and crowding.[88] Several other factors, including neighborhood disadvantage, may also contribute to short sleep duration in Hispanic individuals. It is evident that the environment is an important determinant of sleep health among Hispanic populations and may be a target for intervention.

The neighborhood did not explain Black-White differences in sleep duration. Conversely, prior MESA papers have found the social and built environment to be associated with sleep duration among Black participants.[89] While evidence supports that the environment is important to the sleep of Black populations,[18,23,41,42,71] there may be other factors study as racism or discrimination that may explain the Black-White disparity in sleep duration.[90] Few studies have examined the neighborhood environment and sleep among Chinese participants. In the current study, we found that the proportion of land dedicated retail space attenuated the Chinese-White difference in sleep duration. However, this association should be interpreted with caution given the wide confidence intervals, which may be due to the smaller sample size. Future studies should further explore other factors that may explain the Chinese-White difference in sleep duration.

There are several implications of this research including modifying the environment to promote sleep health. Built environments have positive effects on health outside of sleep, therefore it is important to consider adjustments that also benefit sleep. Future research should aim to identify factors such as housing that may modify the adverse effects of the physical environment. This research could also be used as a tool for advocacy to help improve conditions for those negatively affected by the physical environment. Such advocacy could target noise ordinances or housing that blocks outside noise. Physicians could potentially use these data to identify those who may be at high risk for sleep problems based on their neighborhood environment. These variables could also be included in screening tools to identify risk for adverse sleep health. Our findings suggest that targeting elements of the physical environment, such as aesthetic quality, walking destination density, land zoning, and population density, may reduce sleep disparities between Hispanic and White individuals. Our findings are significant because we identified specific features of the physical environment that may explain Hispanic-White differences in sleep duration.[91–93] Furthermore, short sleep duration has been linked to a higher prevalence of cardiovascular risk factors, as well as increased risk of cardiovascular disease, which is more prevalent among racial minorities.[93–96] Therefore, to eliminate heath disparities, it is critical to explore the factors that shape sleep duration and quality among racial minorities.

Our study has many strengths including the use of objective actigraphy data. Actigraphy measured sleep is an accurate measure that allows us to objectively measure sleep patterns over several days.[97–99] Additionally, we investigated potential pathways for racial disparities in sleep.

We included objective measures of the physical environment (walking destination density, proportion of land dedicated to retail space, and the built environment factor score), which reduces potential measurement error in characterizing the neighborhood environment. This study was conducted among a multi-ethnic sample, thus increasing the diversity of the neighborhood-sleep literature. There are also limitations to this research. Land-use data was collected from several sources over different years. The use of parcel data to estimate land-use negates vertical development and zoning based on land use may not always be accurate to what is in that space. Although this study samples a geographically diverse and multi-ethnic cohort, the results may not be generalizable for younger populations or individuals outside of the 6 study areas. Additionally, this study did not capture housing conditions, which have been found to have a negative impact on sleep health.[45,61] Unfavorable housing is more common among Black populations, and housing types have been found to have a negative impact on sleep health.[45,61] Finally, our study examined cross-sectional associations; therefore, we are not able to determine causal relationships.

This study provides evidence that Hispanic-White differences in sleep duration are partially explained by the physical environment. The findings from this study can be used to inform interventions by identifying the physical environment features that may be salient for certain racial groups. Intervention on the neighborhood level could improve sleep health for minorities. Future research should continue to explore other areas of the physical environment that influence sleep behaviors and the pathway. A push for collaboration between public health officials, physicians, and urban planners will be critical in closing the gap in racial sleep disparities.

TABLES AND FIGURES

Table 1. Sociodemographic, Physical Environment, and Sleep by Race Category, Examination 5, Multi-Ethnic Study of Atherosclerosis (N=2020).

Variables	Overall, mean ± SD or % N=2020	White, mean ± SD or % N=762	Black, mean ± SD or % N=565	Hispanic, mean ± SD or % N=463	Chinese, mean ± SD or % N= 230	Race Difference, p-value
Age (years)	68.5 (9.1)	68.9 (9.2)	68.3 (8.9)	68.4 (9.4)	67.5 (8.9)	0.63
Male, %	928 (45.9%)	357 (47.0%)	248 (43.9%)	215 (46.4%)	108 (47.0%)	0.72
Education						<0.01
<High School	312 (17.8%)	123 (18.5%)	61 (12.6%)	70 (17.5%)	58 (28.9%)	
High school/GED	413 (23.6%)	156 (23.4%)	120 (24.8%)	89 (22.3%)	48 (23.9%)	
Some college	341 (19.5%)	146 (22.0%)	91 (18.8%)	70 (17.7%)	34 (16.9%)	
>College	683 (39.1%)	241 (36.2%)	211 (43.7%)	170 (42.6%)	61 (30.4%)	
Household income, %						<0.01
<$25,000	511 (25.9%)	86 (11.6%)	127 (23.0%)	203 (45.0)	95 (41.7)	
$25,000-$49,000	556 (28.1%)	189 (25.5%)	190 (34.5%)	136 (30.2%)	41 (18.0)	
$50,000-$74,000	353 (17.9%)	155 (20.9%)	97 (17.6%)	67 (14.9%)	34 (14.9)	
$75,000+	551 (28.0%)	311 (42.0%)	137 (24.9%)	45 (10.0%)	58 (25.4)	
Married, %	1205 (59.7%)	462 (60.6%)	361 (64.2%)	275 (59.5%)	107 (46.5%)	<0.01
Currently Employed, %	1120 (55.5%)	433 (56.8%)	311 (55.0%)	257 (55.5%)	119 (51.7%)	0.35
BMI (kg/m2)	28.8 (5.6)	28.1 (5.4)	30.5 (5.6)	30.2 (5.4)	24.3 (3.4)	<0.01
BMI category, %						<0.01
BMI < 25 kg/m2	538 (26.6%)	236 (31.0%)	90 (15.9%)	71 (15.3%)	141(61.3%)	
BMI = 25-29 kg/m2	759 (37.6%)	297 (39.0%)	197 (34.8%)	188 (40.6%)	77(33.5%)	
BMI ≥ 30 kg/m2	723 (35.8%)	229 (30.0%)	278 (49.2)	204 (44.1%)	12 (5.2%)	
CES-D score	7.44(7.2)	7.03(6.9)	7.34 (7.2)	8.86 (8.1)	6.18 (5.7)	<0.01
Average Sleep Time in minutes	389.1 (80.9)	409.8 (71.7)	361.9 (83.1)	380.2 (80.8)	392.5 (82.6)	<0.01
%Short Sleep Duration						
<420 minutes (7 hours)	1269 (62.8%)	397 (52.1%)	432 (76.4%)	291 (62.8%)	149 (64.8%)	<0.01
<360 minutes (6 hours)	628 (31.1%)	146 (19.2%)	250 (44.3%)	149 (32.2%)	83 (36.1%)	<0.01
Physical Environment						
Availability of healthy food (0-5)	3.92 (0.97)	3.95 (0.99)	3.73 (1.07)	4.09 (0.89)	3.96 (0.67)	<0.01
Aesthetic Quality (0-5)	3.86 (0.72)	3.95 (0.67)	3.91 (0.74)	3.64 (0.77)	3.85 (0.57)	<0.01
Walking Environment (0-5)	4.05 (0.65)	4.15 (0.68)	3.98 (0.66)	4.07(0.58)	3.91 (0.60)	<0.01
Walking destination density (0 - 790)	79.4 (117.4)	74.5 (125.9)	62.7 (101.7)	123.6 (131.9)	47.2 (49.9)	<0.01
Proportion retail (0 - 0.19)	0.05 (0.03)	0.05 (0.04)	0.05 (0.04)	0.06 (0.03)	0.06 (0.03)	<0.01
Built Environment Factor Score (-3.0 - 6.9)	0.1 (2.3)	-0.1 (2.1)	-0.1 (2.3)	1.3 (2.7)	-0.8 (1.0)	<0.01

*P <0.05, ** P<0.01

Table 2: Pearson Correlation Coefficients of physical environment measures.

	Availability of Healthy Food	Aesthetic Quality	Walking Environment	Proportion Retail	Walking Destination Density
Availability of Healthy Food	1				
Aesthetic Quality	0.128**	1			
Walking Environment	0.359**	0.352**	1		
Proportion Retail	0.123**	-0.199**	0.081**	1	
Walking Destination Density	0.134**	-0.293**	0.123**	0.557**	1

*P <0.05, ** P<0.01

Table 3. Adjusted beta estimates and prevalence ratios for continuous sleep and sleep time less than 6 hours and physical environment measures, N= 2020.

	Continuous sleep duration (minutes)				Short sleep <6 hours vs ≥6 hours			
	Model 1		Model 2		Model 1		Model 2	
	β	95%	β	95%	PR	95%	PR	95%
Availability of Healthy Food	2.5	(-1.0, 6.0)	-0.5	(-3.9, 3.0)	0.95	(0.90, 1.00)	0.98	(0.92, 1.04)
Aesthetic Quality	5.0*	(1.5, 8.5)	4.5*	(0.9, 8.0)	0.87**	(0.84, 0.94)	0.91*	(0.86, 0.97)
Walking Environment	1.2	(-2.3, 4.8)	-1.4	(-4.9, 2.1)	0.96	(0.90, 1.02)	1.00	(0.93, 1.06)
Walking Destination Density	-5.2**	(-8.8, -1.7)	-8.1**	(-11.6, -4.7)	1.11**	(1.05, 1.17)	1.10**	(1.04, 1.16)
Proportion Retail	-5.8**	(-9.3, -2.2)	-6.5**	(-9.9, -3.0)	1.11**	(1.04, 1.17)	1.11**	(1.04, 1.18)
Built Environment Factor Score	-6.1	(-9.7, -2.6)	-8.8**	(-12.3, -5.3)	1.05**	(1.03,1.08)	1.05**	(1.02, 1.07)

Model 1 adjusts for age and gender. Model 2 adjusts for age, gender, household income, education, marital status, employment, BMI, and CES-D
*P<0.05, **P<0.01

Table 4. Multi-level linear regression models demonstrating racial disparities in sleep in the sample (n=2020) after adjusting for covariates and features of the physical environment, N=2020

	Model 1		Model 2		Model 3	
Variables	*β*	95% CI	*β*	95% CI	*β*	95% CI
Race (White = ref)						
Black	-48.7**	(-57.1, -40.2)	-44.8**	(-53.5, -36.1)	-44.9**	(-53.6, -36.1)
Hispanic	-17.2*	(-26.1, -8.3)	-10.4**	(-20.1, -0.7)	-10.3*	(-20.1, -0.5)
Chinese	-28.9**	(-40.3, -17.5)	-31.4*	(-43.5, -19.3)	-31.4**	(-43.5, -19.3)
Age	0.4 *	(0.1, 08)	0.4*	(0.0, 0.8)	0.4	(0, 0.8)
Male	-28.9**	(-35.7, -22.2)	-30.4**	(-37.3, -23.4)	-30.4**	(-37.3, -23.4)
Education			-0.7	(-2.2, 0.9)	-0.6	(-2.1, 0.9)
Employed			-0.1	(-1.2, 0.9)	-0.1	(-1.2, 0.9)
Married			-2.7*	(-5.2, -0.2)	-2.8*	(-5.3, -0.3)
Household Income (per $1000)			0.9	(-0.2, 2.0)	1	(-0.13, 2.02)
BMI			-1.3**	(-1.9, -0.6)	-1.3**	(-1.9, -0.60)
CES-D			-0.8**	(-1.3, -0.3)	-0.8**	(-1.3, -35)
Physical Environment						
Availability of healthy food					-0.5	(-3.9, 3.0)
Aesthetic quality						
Walking environment						
Walking destination density						
Proportion retail						
Built Environment Factor Score						

*P<0.05, **P<0.01

Table 4 continued

	Model 2		Model 4		Model 5	
Variables	β	95% CI	β	95% CI	β	95% CI
Race (White = ref)						
Black	-44.8**	(-53.5, -36.1)	-45.0**	(-53.7, -36.2)	-45.0**	(-53.8, -36.2)
Hispanic	-10.4**	(-20.1, -0.7)	-9.5	(-19.2, 0.3)	-10.3*	(-20.0, -0.5)
Chinese	-31.4*	(-43.5, -19.3)	-31.5**	(-43.6, -19.5)	-31.8**	(-43.9, -19.7)
Age	0.4*	(0.0, 0.8)	0.4	(-0.1, 0.8)	0.4	(0, 0.8)
Male	-30.4**	(-37.3, -23.4)	-30.1**	(-37.6, -23.6)	-30.8**	(-37.8, -23.8)
Education	-0.7	(-2.2, 0.9)	0.6	(-0.5, 1.7)	1.0	(-0.1, 2.1)
Employed	-0.1	(-1.2, 0.9)	-0.7	(-2.2, 0.8)	-0.7	(-2.2, 0.8)
Married	-2.7*	(-5.2, -0.2)	-2.8*	(-5.3, -0.3)	-2.8*	(-5.2, -0.2)
Household Income (per $1000)	0.9	(-0.2, 2.0)	-0.1	(-1.0, 0.9)	-0.2	(-1.2, -0.9)
BMI	-1.3**	(-1.9, -0.6)	-1.3**	(-2.0, -0.6)	-1.3**	(-1.9, -0.6)
CES-D	-0.8**	(-1.3, -0.3)	-0.7**	(-1.2, -0.2)	-0.8**	(-1.3, -0.3)
Physical Environment	-44.8**	(-53.5, -36.1)				
Availability of healthy food						
Aesthetic quality			4.5*	(0.9, 8.1)		
Walking environment					-1.4	(-4.9, 2.1)
Walking destination density						
Proportion retail						
Built Environment Factor Score						

*P<0.05, **P<0.01

Table 4 continued.

	Model 2		Model 6		Model 7	
Variables	*β*	95% CI	*β*	95% CI	*β*	95%CI
Race (White = ref)						
Black	-44.8**	(-53.5, -36.1)	-45.4**	(-54.1, -36.7)	-45.3**	(-54.0, -36.5)
Hispanic	-10.4**	(-20.1, -0.7)	-6.7	(-16.5, 3.1)	-9.0	(-18.7, 0.8)
Chinese	-31.4*	(-43.5, -19.3)	-33.3**	(-45.4, -21.3)	-29.0**	(-41.2, -16.9)
Age	0.4*	(0.0, 0.8)	0.4*	(0.1, 0.8)	0.4	(0, 0.8)
Male (Female = ref)	-30.4**	(-37.3, -23.4)	-32.1**	(-39.0, -25.1)	-31.3**	(-38.2, -24.4)
Education	-0.7	(-2.2, 0.9)	1.0	(-0.1, 2.0)	0.8	(-0.3, 1.9)
Employed	-0.1	(-1.2, 0.9)	-0.5	(-2.0, 1.0)	-0.7	(-2.2, 0.8)
Married	-2.7*	(-5.2, -0.2)	-3.0*	(-5.5, -0.5)	-2.7*	(-5.1, -0.1)
Household Income (per $1000)	0.9	(-0.2, 2.0)	-0.2	(-1.2, 0.9)	-0.2	(-1.2, 0.9)
BMI			-1.3**	(-2.0, -0.7)	-1.3**	(-2.0, -0.7)
CES-D			-0.7**	(-1.2, -0.2)	-0.7**	(-1.2, -0.3)
Physical Environment						
Availability of healthy food						
Aesthetic quality						
Walking environment						
Walking destination density			-8.2**	(-11.6, -4.7)		
Proportion retail					-6.5**	(-9.9, 3.0)
Built Environment Factor Score						

*P<0.05, **P<0.01

Table 4 continued.

	Model 2		Model 8	
Variables	β	95% CI	β	95% CI
Race (White = ref)				
Black	-44.8**	(-53.5, -36.1)	-44.7**	(-53.4 -36.0)
Hispanic	-10.4**	(-20.1, -0.7)	-4.8	(-14.7, 5.1)
Chinese	-31.4*	(-43.5, -19.3)	-34.0**	(-46.0, -21.9)
Age	0.4*	(0.0, 0.8)	-0.4*	(0.1, 0.8)
Male (Female = ref)	-30.4**	(-37.3, -23.4)	-32.0**	(-37.0, -25.1)
Education	-0.7	(-2.2, 0.9)	0.9	(-0.2, 2.0)
Employed	-0.1	(-1.2, 0.9)	-0.5	(-2.0, 1.0)
Married	-2.7*	(-5.2, -0.2)	-3.1*	(-5.6, -0.6)
Household Income (per $1000)	0.9	(-0.2, 2.0)	-0.1	(-1.2, 0.9)
BMI			-1.4**	(-2.0, -0.7)
CES-D			-0.7**	(-1.2, -0.2)
Physical Environment				
Availability of healthy food				
Aesthetic quality				
Walking environment				
Walking destination density				
Proportion retail				
Built Environment Factor Score			-8.8**	(-12.4, -5.3)

*P<0.05, **P<0.01

Table 5. Multi-level Poisson regression models with robust variance demonstrating racial difference in short sleep prevalence after adjusting for covariates and elements of the physical environment, N=2020

	White		Black		Hispanic		Chinese	
	PR	95% CI	PR	95% CI	PR	95% CI	PR	95% CI
Model 1	ref	ref	2.34**	(1.97, 2.77)	1.68**	(1.36, 2.07)	1.88**	(1.51, 2.35)
Model 2	ref	ref	2.17**	(1.81, 2.60)	1.48**	(1.18, 1.84)	2.04**	(1.62, 2.58)
Model 3	ref	ref	2.16**	(1.81, 2.59)	1.48**	(1.18, 1.84)	2.05**	(1.62, 2.58)
Model 4	ref	ref	2.17**	(1.82, 2.60)	1.45**	(1.16, 1.80)	2.05**	(1.62, 2.59)
Model 5	ref	ref	2.18**	(1.82, 2.61)	1.47**	(1.18, 1.84)	2.06**	(1.64, 2.59)
Model 6	ref	ref	2.20**	(1.84, 2.63)	1.40**	(1.13, 1.74)	2.13**	(1.68, 2.69)
Model 7	ref	ref	2.19**	(1.83, 2.62)	1.45**	(1.67, 1.81)	1.97**	(1.57, 2.49)
Model 8	ref	ref	2.17**	(1.81, 2.59)	1.36**	(1.09, 1.69)	2.14**	(1.69, 2.70)

Abbreviations: CI, confidence interval; PR, prevalence ratio.
Model 1was adjusted for age and gender.
Model 2 was adjusted age, gender, education, income, employment, marital status, body mass index, and depressions symptoms, as measured using the Center for Epidemiologic Studies-Depression Scale.
Model 3 was adjusted for variables in Model 2 and availability of health food.
Model 4 was adjusted for variables in Model 2 and aesthetic quality.
Model 5 was adjusted for variables in Model 2 and walking environment.
Model 6 was adjusted for variables in Model 2 and walking destination density.
Model 7 was adjusted for variables in Model 2 and proportion of land dedicated to retail space.
Model 8 was adjusted for variables in Model 2 and the built environment factor score.
*P<0.05, **P<0.01

Figure 1. Distribution of Sleep

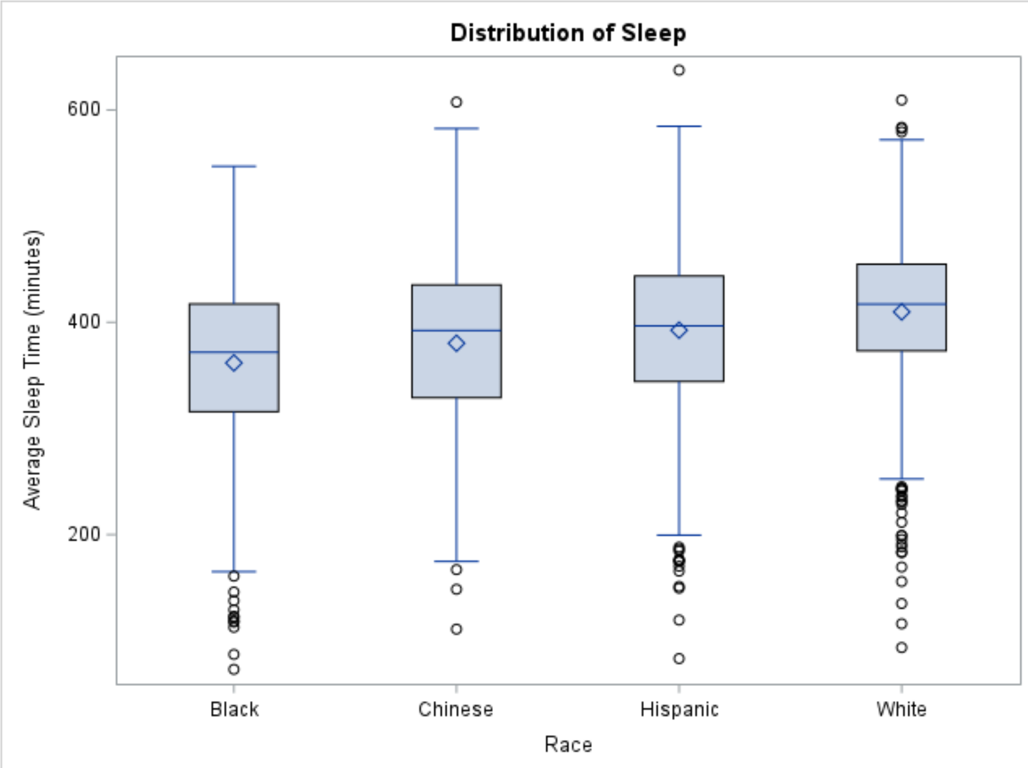


Figure 2. Distribution of Availability of Healthy Food

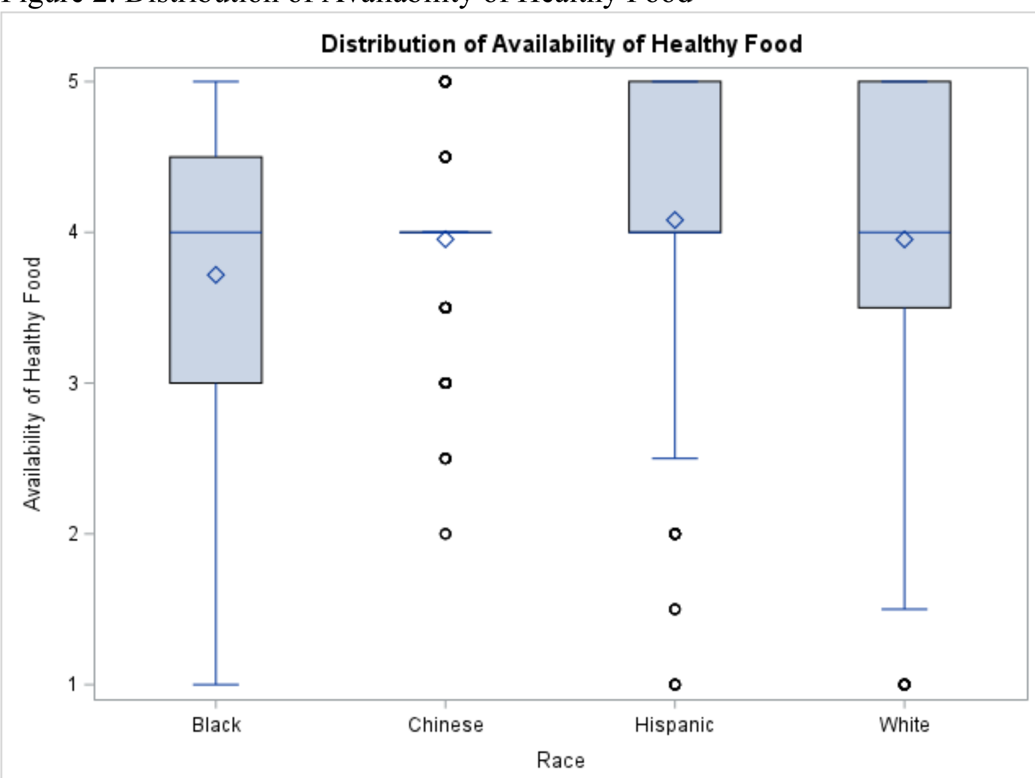


Figure 3. Distribution of Aesthetic Quality

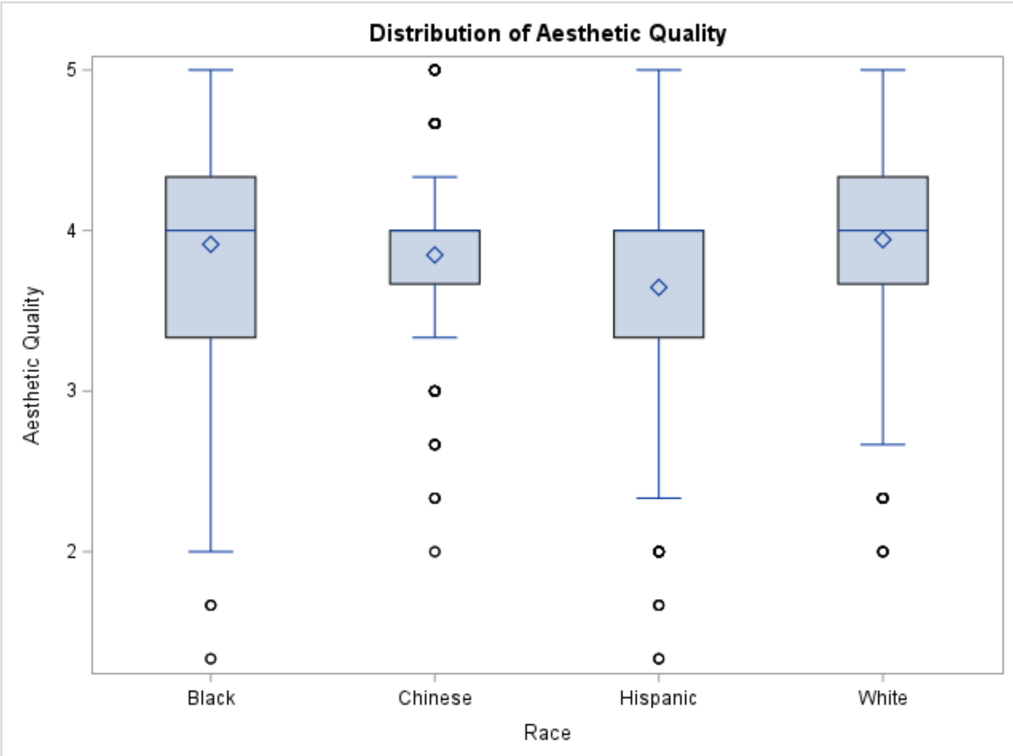


Figure 4. Distribution of Walking Destination Density

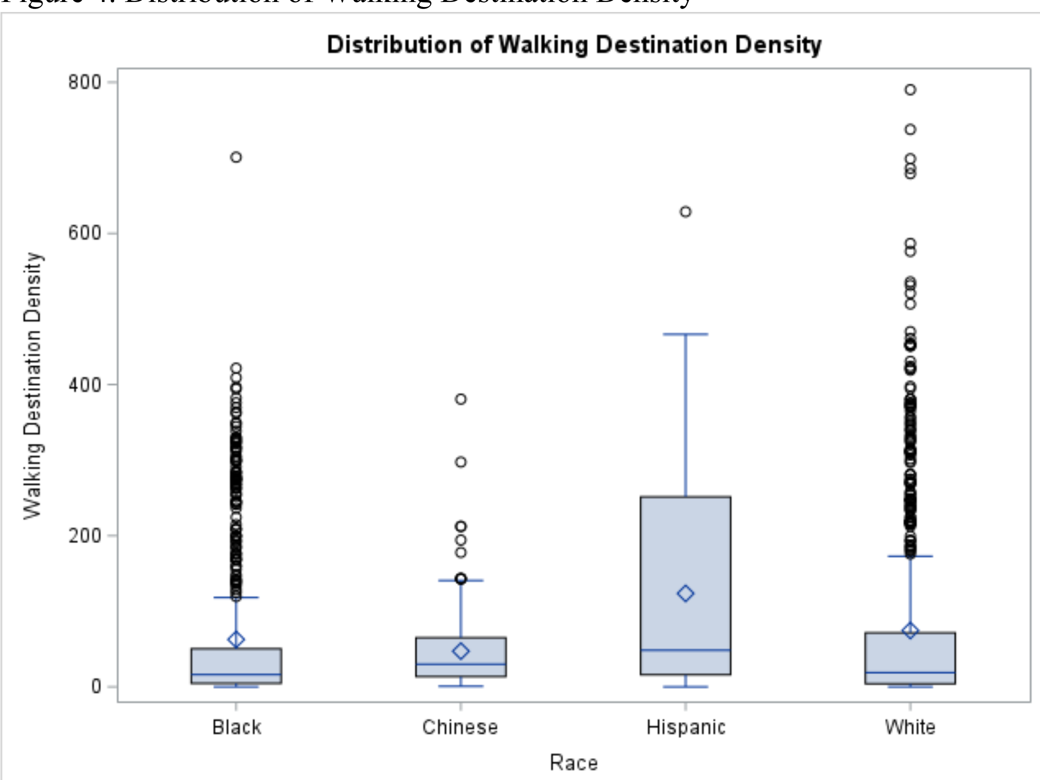


Figure 5. Distribution of Proportion Retail

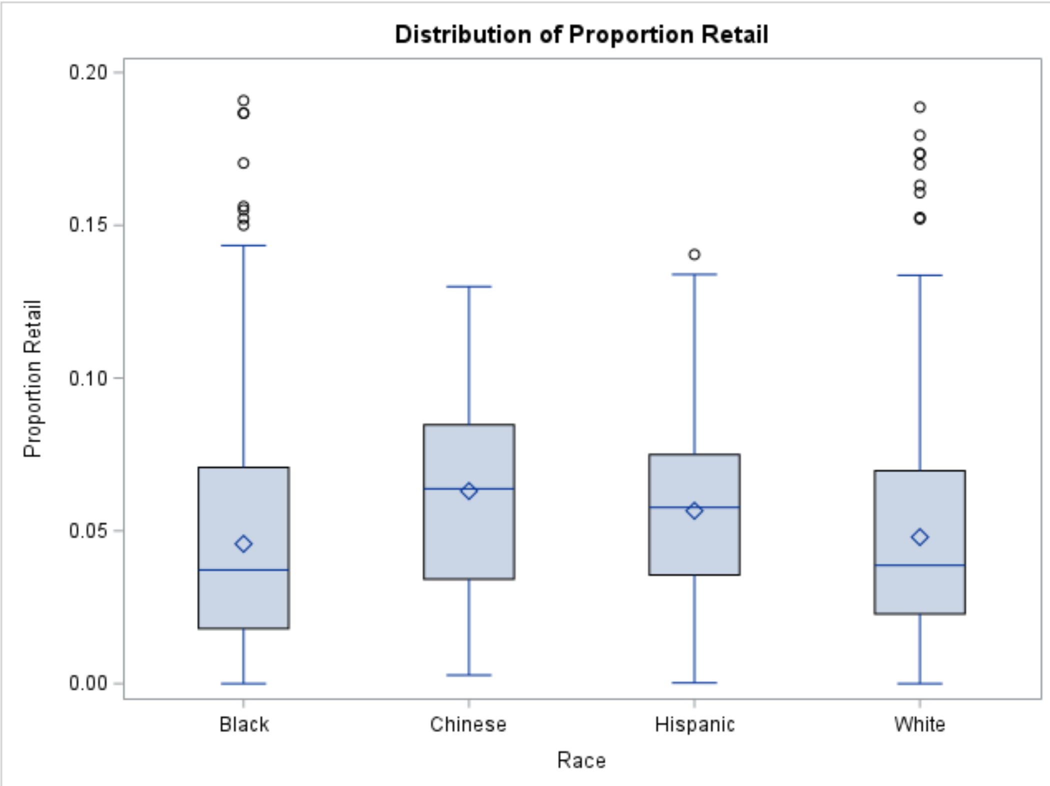


Figure 6. Distribution of Walking Environment

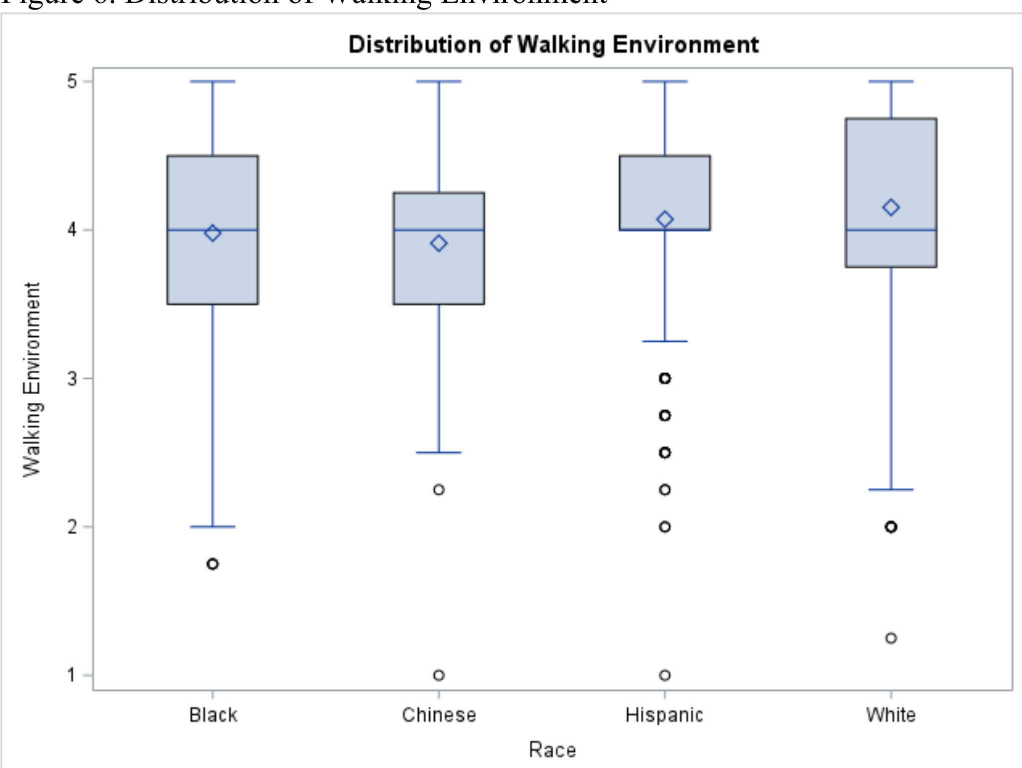
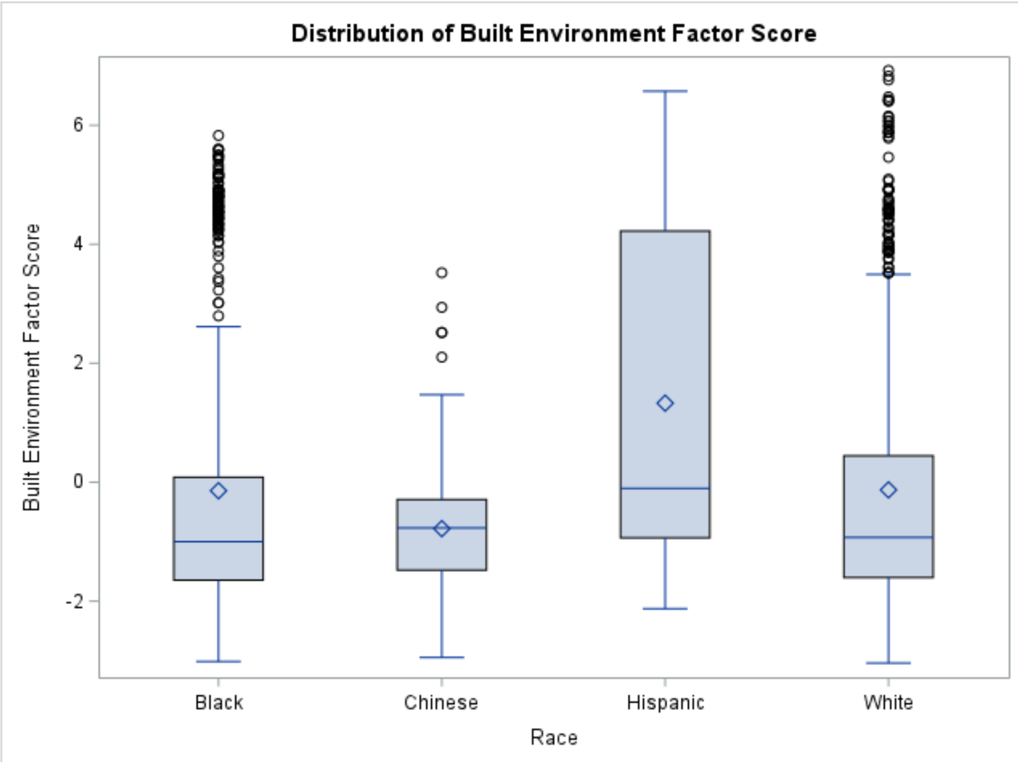


Figure 7. Distribution of Built Environment Factor Score



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APPENDIX
Table 1

	Null model with sleep duration	Model with physical environment feature
Availability of healthy food	0.13%	0.09%
Aesthetic quality	0.13%	0.24%
Walking environment	0.13%	0.13%
Walking destination density	0.13%	0%
Proportion retail	0.13%	0.41%
Built environment factor score	0.13%	0.01%