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Examining the influence of built environment on sleep disruption

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Background: Modifying aspects of the built environment may be an effective strategy for population-level improvements to sleep. However, few comprehensive evaluations of built environment and sleep have been completed.

Methods: We conducted a cross-sectional study among participants of the British Columbia Generations Project (BCGP) who self-reported sleep duration (n = 28,385). Geospatial measures of light-at-night (LAN), greenness, air pollution ($PM_{2.5}$, NO_2, SO_2), and road proximity were linked to participant baseline residential postal codes. Logistic regression models, adjusted for age and sex, were used to estimate the association between these factors and self-reported sleep duration (<7 vs. ≥7 hours).

Results: Interquartile range (IQR) increases in LAN intensity, greenness, and SO_2 were associated with 1.04-fold increased (95% CI = 1.02, 1.07), 0.95-fold decreased (95% CI = 0.91, 0.98), and 1.07-fold increased (95% CI = 1.03, 1.11) odds, respectively, of reporting insufficient sleep (i.e., <7 hours per night). Living <100 m from a main roadway was associated with a 1.09-fold greater odds of insufficient sleep (95% CI = 1.02, 1.17). Results were unchanged when examining all factors together within a single regression model. In stratified analyses, associations with SO_2 were stronger among those with lower reported annual household incomes and those living in more urban areas.

Conclusions: BCGP's rich data enabled a comprehensive evaluation of the built environment, revealing multiple factors as potentially modifiable determinants of sleep disruption. In addition to longitudinal evaluations, future studies should pay careful attention to the role of social disparities in sleep health.

Keywords: Sleep; Built Environment; Air Pollution; Greenness; Light pollution; Road proximity

Introduction

The US Centers for Disease Control has estimated that only 65% of adults obtain sufficient sleep.[1] The Canadian Health Measures Survey noted that 43% of men and 55% of women aged 18–64 had trouble falling asleep or staying asleep.[2] Insufficient sleep has been linked to multiple chronic diseases, including obesity, diabetes, cardiovascular disease, and mental illness.[1] Insufficient sleep is also associated with daytime sleepiness, which can lead to workplace accidents that result in absenteeism and loss of productivity.[1,3] Canada incurs an estimated $21.4 billion annual loss in gross domestic product due to insufficient sleep.[4]

There is growing evidence that modifying features of the built environment may be a strategy for reducing the significant health and economic burdens of insufficient sleep. For example, light-at-night (LAN) is a feature of the built environment that has long been suspected to negatively impact sleep. Indeed, studies have shown that LAN, through suppression of melatonin secretion, disrupts circadian rhythms resulting in later sleep onset,[5] and multiple studies have identified a negative relation between outdoor LAN, as measured by satellite, and sleep duration.[6–10] However, many of these studies have been small in size and most have focused on younger populations (i.e., 20–30 years of age).[11]

Higher levels of greenness may be beneficial to sleep through enhanced mental health, reduced stress, increased opportunities for physical activity, and masking of noise pollution.[12,13] A recent review reported that 11 of 13 studies identified a positive relation between greenness and sleep.[13] However, results were not consistent across all subpopulations and the specific aspects of greenness that were evaluated. For instance, one study found that only tree canopy exposure was significantly associated with sleep,[14] while another observed that negative impacts of reduced greenness on sleep were specific to men.[15] Studies of the impacts of air pollution on sleep have primarily focused on sleep disordered breathing, with most demonstrating significant associations with various pollutants including fine particulate

What this study adds

Ours is one of the very few studies that has comprehensively evaluated the potential impacts of multiple built environment factors on sleep disruption. Our approach is valuable because it allows us to identify the specific factors that may impact sleep so that future studies can examine if modification of these factors can be used to improve sleep health at a population-level.

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Requests for data can be made with an application to the BC Generations Project. Please see website (https://www.bcgenerationsproject.ca/researchers/requesting-data-and-biosample-access/) for more information.

J.P., P.B., and M.B. all came up with the project concept. J.P. developed the data analysis plan with input from P.B. and M.B. J.P. conducted the analysis, with J.P. and P.B. interpreting the results. All authors contributed to the writing of the manuscript.

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matter ($PM_{2.5}$), black carbon, nitrogen dioxide (NO_2), and sulfur dioxide (SO_2).[16–20]

Although several studies have explored how individual aspects of the built environment independently affect sleep, few have taken a comprehensive approach by assessing multiple built environment exposures concurrently.[21] Given the potential for built environment factors to be correlated, multiexposure evaluations are needed to identify the specific factors that are associated with sleep. We conducted such an analysis using data from a large population-based cohort study.

Methods

The study was approved by the BC Cancer/University of British Columbia Research Ethics Board (H22-01080).

Study population

The British Columbia Generations Project (BCGP) is a cohort of 29,736 women and men who were recruited between 2009 and 2016, at the ages of 35–69, from around the province of British Columbia.[22] Participants' baseline residential addresses cover an area of ~65,000 km^2. Participants completed a questionnaire at time of recruitment, providing information on a variety of factors including sex, ethnicity, household income, education level, current medication use, sleep duration, and height and weight for the calculation of body mass index (BMI).

Sleep duration

Participants reported how many hours they slept, on average, each night from a list of options presented in 1-hour intervals. Seven hours/night was the most frequently reported duration of sleep. We dichotomized sleep duration as less than 7 hours versus seven or more hours of sleep per night for our analyses, based on the recommendation that adults get at least 7 hours of sleep per night for optimal health.[23,24]

Built environment

Each participant's six-digit residential postal code at baseline was linked to spatially resolved LAN, greenness, air pollution, and road proximity data curated and provided by the Canadian Urban Environmental Health Research Consortium (CANUE).[25,26] Postal codes in which BCGP participants resided had a median area of ~8,600 m^2, ranging from ~120 to 120,000 m^2. Greenness, NO_2, and $PM_{2.5}$ data were provided for the years 2009–2016, while LAN and SO_2 were provided for the years 2009–2015. Exposure data corresponding to each participant's baseline year were selected for our study. For participants recruited in 2016, LAN and SO_2 exposure levels from 2015 were selected. Participant residential postal codes were also linked to the British Columbia Community Health Service Area boundary map for urban/rural classification into 1 of 7 categories generated by the British Columbia Ministry of Health: metropolitan, large urban, medium urban, small urban, rural hub, rural, and remote.[27]

Outdoor light-at-night

Outdoor LAN intensity data were obtained by CANUE from Version 4 of the Defense Meteorological Program (DMSP) Operational Line-Scan System (OLS) Nighttime Lights Time Series available through Google Earth Engine, which consists of cloud-free composites of data for a resolution of about 1 km (30 arc second grids, spanning −180 to 180 degrees longitude and −65 to 75 degrees latitude) compiled for each calendar year.[28,29] The OLS measures LAN intensity with a six-bit quantization radiometric resolution which is expressed as a unitless digital number (DN) ranging in value from 0 to 63. Only persistent lighting was included in the measures, such as lights from cities, towns, and gas flares. Light from events such as fires were not included, and background noise was identified and assigned a value of zero.[28,29]

Greenness

Cloud-free surface reflectance satellite data, from the US Geological Survey's Landsat 5 and Landsat 8 satellites, were accessed via Google Earth Engine and were used by CANUE to generate cloud-free annual mean normalized difference vegetation index (NDVI) values for each postal code, at a spatial resolution of 30 m for each year. Google Earth Engine functions also allowed for water features to be masked. The NDVI ranged from −1 to +1, where −1 represented barren land and +1 represented a high density of vegetation.[26,29] Only NDVI measures of greenspace were made available.

Air pollution

Ground-level $PM_{2.5}$ measures (μg/m^3) were estimated at one kilometer resolution (or, 0.01 by 0.01 degree gridded surface), using a combination of satellite-based aerosol optical depth measures and a chemical transport model.[26,30,31] Estimates were calibrated with data from regional ground-based observations using geographically weighted regression (GWR). Ground-level SO_2 concentrations (ppb), at 20 km resolution, were estimated using satellite profiles from the Global Environmental Multi-scale-Modelling Air quality and Chemistry (GEM-MACH) model.[32] $PM_{2.5}$ and SO_2 estimates were provided by CANUE for each year as the average of that year plus the two preceding years (e.g., values for 2010 were averages of measures over the years 2008–2010, values for 2011 were averages over the years 2009–2011 etc.). For NO_2, annual average concentrations (ppb) for each six-digit postal code were provided. These were estimated using land use regression (LUR) models with a deterministic gradient that incorporated satellite derived NO_2 measures and data on industrial land use within 2 km, road length within 10 km, and summer rainfall.[26,33,34]

Proximity to roadways

Distances, in meters, from each single-link postal code to the nearest expressway (roadway with four or more lanes with limited access to adjacent land), primary highway (multi-lane roadway for intracity traffic), secondary highway (multi-lane roadway with large traffic capacity), and major roadway (roadway for shorter within city trips) were estimated by CANUE based on the DMTI Spatial Inc. CanMap Content Suite street network files by using PostGreSQL.[35,36] We then derived a single proximity to main roadway variable as the smallest distance (meters) to an expressway, primary highway, secondary highway, or major roadway.

Statistical methods

Logistic regression models, adjusted for age at baseline (continuous) and sex at birth, were used to assess the relation between each built environment factor and self-reported sleep duration as a binary outcome (<7 vs. ≥7 hours). Built environment factors were evaluated as continuous [per interquartile range (IQR)] and categorical variables. For most of the built environment factors, categories were based on quartiles of the continuous distribution. Proximity to main roadway was dichotomized (≥100 vs. <100 m). Associations were calculated as odds ratios (ORs) with 95% confidence intervals (95% CI). Ethnicity, annual household income, education level, BMI, smoking status, and use of hypnotic/sedative medication(s) were evaluated as potential confounding factors in the subset of the study population that had nonmissing values for each of these factors. Inclusion of these variables had minimal impact on effect estimates of interest (<10%), so they were not included in the final regression models. We conducted exploratory stratified analyses of the continuous exposure variables by sex, annual household income (<\$75,000 vs. ≥\$75,000/year) and urbanicity (metropolitan and large urban centers vs. median urban centers, small urban centers, rural hubs, rural centers, and remote areas). Statistical significance of strata-specific differences was assessed by including exposure-sex, exposure-income, and exposure-urbanicity cross-products terms in separate regression models.

Table 1.

Demographics, sleep duration, and built environment factors in the BC Generations Project.

Characteristic	N	% or Mean (SD)
Age at enrollment	28,385	56.3 (8.9)
Sex		
Female	19,471	68.6%
Male	8,914	31.4%
Sleep duration (h/night)		
≤6	6,856	24.2%
7	10,869	38.3%
8	8,307	29.3%
≥9	2,344	8.3%
Ethnicity		
Non-Hispanic White	20,082	89.8%
Other	2,272	10.2%
Missing	6,031	-
Highest education		
None	13	0.1%
Elementary school	183	0.8%
High school	3,893	17.4%
Trade, technical, or vocational school	2,498	11.2%
Diploma from community college	4,608	20.6%
University certificate below bachelor's level	1,319	5.9%
Bachelor's degree	5,792	25.9%
Graduate degree (MSc, MBA, MD, PhD, etc)	4,048	18.1%
Missing	6,031	-
Annual income		
<\$10,000	202	0.9%
\$10,000–24,999	1,055	4.7%
\$25,000–49,999	3,609	16.1%
\$50,000–74,999	4,766	21.3%
\$75,000–99,999	4,136	18.5%
\$100,000–149,999	4,933	22.1%
\$150,000–199,999	2,066	9.2%
≥\$200,000	1,587	7.1%
Missing	6,031	-
Smoking status		
Never smoked	12,055	53.9%
Past smoker	9,132	40.9%
Current smoker	1,167	5.2%
Missing	6,031	-
Current sedative/hypnotic medication use		
No	21,574	96.5%
Yes	780	3.5%
Missing	6,031	-
Urban/rural classification of baseline residential address		
Metropolitan	12,963	45.8%
Large urban	5,455	19.3%
Medium urban	5,507	19.5%
Small urban	1,755	6.2%
Rural hub	513	1.8%
Rural	2,093	7.4%
Remote	27	0.1%
Missing	72	-
Light-at-night (DN)	28,263	53.4 (14.1)
Greenspace (NDVI)	28,270	0.3 (0.1)
$PM_{2.5}$ (μg/m^3)	28,262	5.2 (1.0)
NO_2 (ppb)	28,264	10.8 (4.5)
SO_2 (ppb)	27,480	0.4 (0.3)
Proximity to main roadway (m)	28,269	490.9 (1,204.7)

Correlations between continuous measures of each built environment factor were assessed using Pearson's correlation coefficient. A multiexposure model was used to evaluate the association between each built-environment factor and insufficient sleep while adjusting for all other built-environment factors as well as age and sex. All analyses were conducted in R version 4.1.0 (The R Foundation for Statistical Computing).

Results

Of the 29,736 BCGP participants, 28,385 had complete data on age, sex, and sleep duration. Mean age at enrollment was 56.3 with a standard deviation (SD) of 8.9 years, and 68.6% of participants were female (Table 1). Participants most commonly reported sleeping an average of 7 hours per night (38.3%). Of those with nonmissing data, 89.8% reported being non-Hispanic White, 81.7% completed some form of postsecondary education, 38.4% reported annual incomes of ≥\$100,000, 53.9% reported never smoking, 96.5% reported no current sedative or hypnotic medication use, and 45.8% lived in metropolitan areas. The number of participants that also had built environment data varied from 27,480 for SO_2 to 28,270 for greenspace.

For each IQR (11 DN) increase of ambient LAN exposure, there was a statistically significant 4% greater odds of reporting <7 hours of sleep per night (OR = 1.04; 95% CI = 1.02, 1.07; Table 2). Compared with those in the lowest quartile of LAN exposure, those in the second and third quartiles had statistically significant 9% (OR = 1.09; 95% CI = 1.01, 1.17) and 15% (OR = 1.15; 95% CI = 1.06, 1.24) greater odds, respectively, of reporting <7 hours of sleep per night. Although the

Table 2.

Association of built environment factors with sleep duration in the BC Generations Project.

Built environment factor (IQR)	N	Odds ratio[a]	95% CI
Light-at-night (11 DN)	28,273	1.04[b]	1.02, 1.07
<51	7,083	1.00	Ref
51–<60	7,042	1.09[c]	1.01, 1.17
60–<62	7,032	1.15[b]	1.06, 1.24
≥62	7,116	1.06	0.98, 1.15
Greenspace (0.2 NDVI)	28,270	0.95[b]	0.91, 0.98
<0.26	7,086	1.00	Ref
0.26–<0.34	7,054	1.02	0.95, 1.10
0.34–<0.43	7,084	0.95	0.88, 1.02
≥0.43	7,046	0.91[b]	0.84, 0.98
$PM_{2.5}$ (1.6 μg/m^3)	28,262	0.95[c]	0.91, 0.99
<4.4	7,095	1.00	Ref
4.4–<5.4	7,072	1.12[b]	1.04, 1.21
5.4–<6.0	7,078	1.00	0.93, 1.08
≥6.0	7,062	0.97	0.90, 1.05
NO_2 (6.3 ppb)	28,273	1.02	0.99, 1.07
<7.3	7,057	1.00	Ref
7.3–<9.8	7,049	0.98	0.91, 1.06
9.8–<13.6	7,076	1.06	0.98, 1.14
≥13.6	7,091	1.07	0.99, 1.15
SO_2 (0.4 ppb)	27,483	1.07[b]	1.03, 1.11
<0.2	6,953	1.00	Ref
0.2–<0.4	6,875	1.10[c]	1.02, 1.19
0.4–<0.5	6,782	1.10[c]	1.01, 1.19
≥0.5 SO_2	6,873	1.22[b]	1.13, 1.32
Distance to main roadway (366.1 m)	28,269	0.98[b]	0.97, 0.99
≥100	22,248	1.00	Ref
<100	6,021	1.09[b]	1.02, 1.17

[a] Adjusted for age at enrollment and sex. For continuous analysis, odds of insufficient sleep (<7 vs. ≥7 h) ratio reported per IQR increase in exposure levels.

[b] $P < 0.01$.

[c] P value <0.05.

Table 3.

Associations of built environment factors with sleep duration, stratified by sex, annual household income, and urbanicity in the BC Generations Project.

	Sex				Annual household income				Urbanicity[d]			
Built environment factor (IQR)[a]		**N**	**OR[b]**	***P*[c]**		**N**	**OR[b]**	***P***		**N**	**OR[b]**	***P***
Light at night (11 DN)	Males	8,881	1.03	0.8	<$75,000	12,691	1.03	0.2	More urban	18,361	1.05	0.9
	Females	19,392	1.05		≥$75,000	9,594	1.06		Less urban	9,843	1.05	
Greenspace (0.17 NDVI)	Male	8,880	0.98	0.5	<$75,000	12,688	0.93	0.3	More urban	18,362	0.94	0.5
	Female	19,390	0.93		≥$75,000	9.593	0.98		Less urban	9,839	0.96	
PM$_{2.5}$ air pollution (1.6-1.7 µg/m^3)	Male	8,874	0.99	0.1	<$75,000	12,684	0.94	0.2	More urban	18,353	0.90	0.4
	Female	19,388	0.93		≥$75,000	9,590	1.01		Less urban	9,840	0.94	
NO$_2$ air pollution (6.3 ppb)	Male	8,880	1.02	0.5	<$75,000	12,690	1.00	0.1	More urban	18,360	1.02	0.5
	Female	19,393	1.03		≥$75,000	9,595	1.07		Less urban	9,844	0.97	
SO$_2$ air pollution (0.36–0.38 ppb)	Male	8,644	1.08	0.7	<$75,000	12,385	1.03	0.01	More urban	17,949	1.11	0.03
	Female	18,839	1.07		≥$75,000	9,313	1.15		Less urban	9,466	1.02	
Distance to main roadway (366.1–373.7 m)	Male	8,040	0.99	0.6	<$75,000	12,691	0.99	0.6	More urban	18,363	0.99	0.9
	Female	17,578	0.98		≥$75,000	9,595	0.98		Less urban	9,837	0.99	

[a] IQR may vary across the different stratified analyses given differences in exposure distribution in each subsample with complete data inclusive of the stratification variable.

[b] Odds of insufficient sleep (<7 vs. ≥7 h) ratio reported per IQR increase in exposure levels, adjusting for age at enrollment and sex.

[c] Interaction *P* value for cross-products terms in the logistic regression models.

[d] Those who were classified as living in a large urban center or metropolitan center were considered "More urban" dwellers, while those from medium or small urban centers, or rural hubs or remote or rural centers were considered "Less urban" dwellers.

odds of reporting insufficient sleep were elevated among those with the highest quartile of LAN exposure, the association was not statistically significant (OR = 1.06; 95% CI = 0.98, 1.15). Each IQR increase in greenspace (NDVI 0.17) was associated with a statistically significant 5% lower odds of reporting insufficient sleep (OR = 0.95; 95% CI = 0.91, 0.98). Compared with the lowest greenspace quartile, a statistically significant 9% decrease in odds of reporting insufficient sleep was found among those in the highest quartile (OR = 0.91; 95% CI = 0.84, 0.98). Each IQR (1.6 µg/m^3) increase in PM$_{2.5}$ exposure was associated with a statistically significant 5% decreased odds of insufficient sleep (OR = 0.95; 95% CI = 0.91, 0.99). However, in categorical analyses, a statistically significant 12% increased odds of reporting <7 hours of sleep per night was observed when comparing the second and first quartiles of PM$_{2.5}$ exposure (OR = 1.12; 95% CI = 1.04, 1.21), with no significant results observed among the other quartiles. No statistically significant associations were observed with NO$_2$ exposure. Each IQR (0.4 ppb) increase in SO$_2$ exposure was statistically significantly associated with reporting shorter sleep duration (OR = 1.07; 95% CI = 1.03, 1.11). In categorical analysis, statistically significant 10%, 10% and 22% increased odds of reporting insufficient sleep were observed among those in the second (OR = 1.10; 95% CI = 1.02, 1.19), third (OR = 1.10; 95 CI = 1.01, 1.19), and fourth (OR = 1.22; 95% CI = 1.13, 1.32) quartiles of SO$_2$ exposure, respectively, when compared with the lowest quartile of exposure. Each IQR (366.1 m) increase in distance to main roadway was associated with a 2% decrease in odds of reporting <7 hours of sleep/night (OR = 0.98; 95% CI = 0.97, 0.99). In categorical analysis, those living <100 m from a main roadway

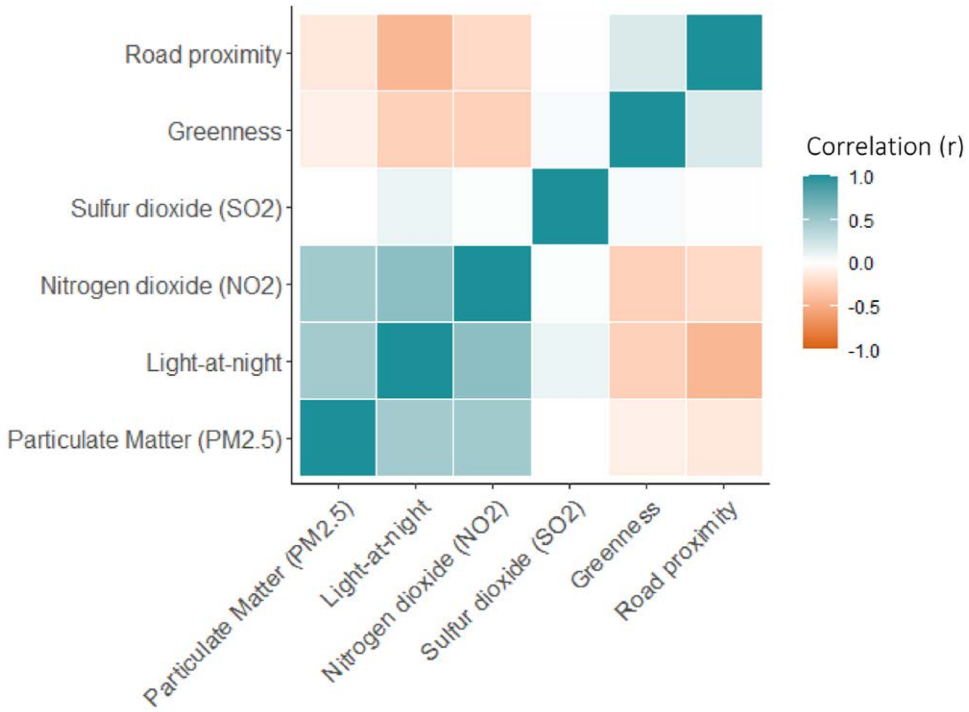

Figure 1. Correlation of built environment factor measures. Turquoise values indicate a positive correlation while orange values indicate a negative correlation. The darkness of the square indicates the magnitude of the correlation.

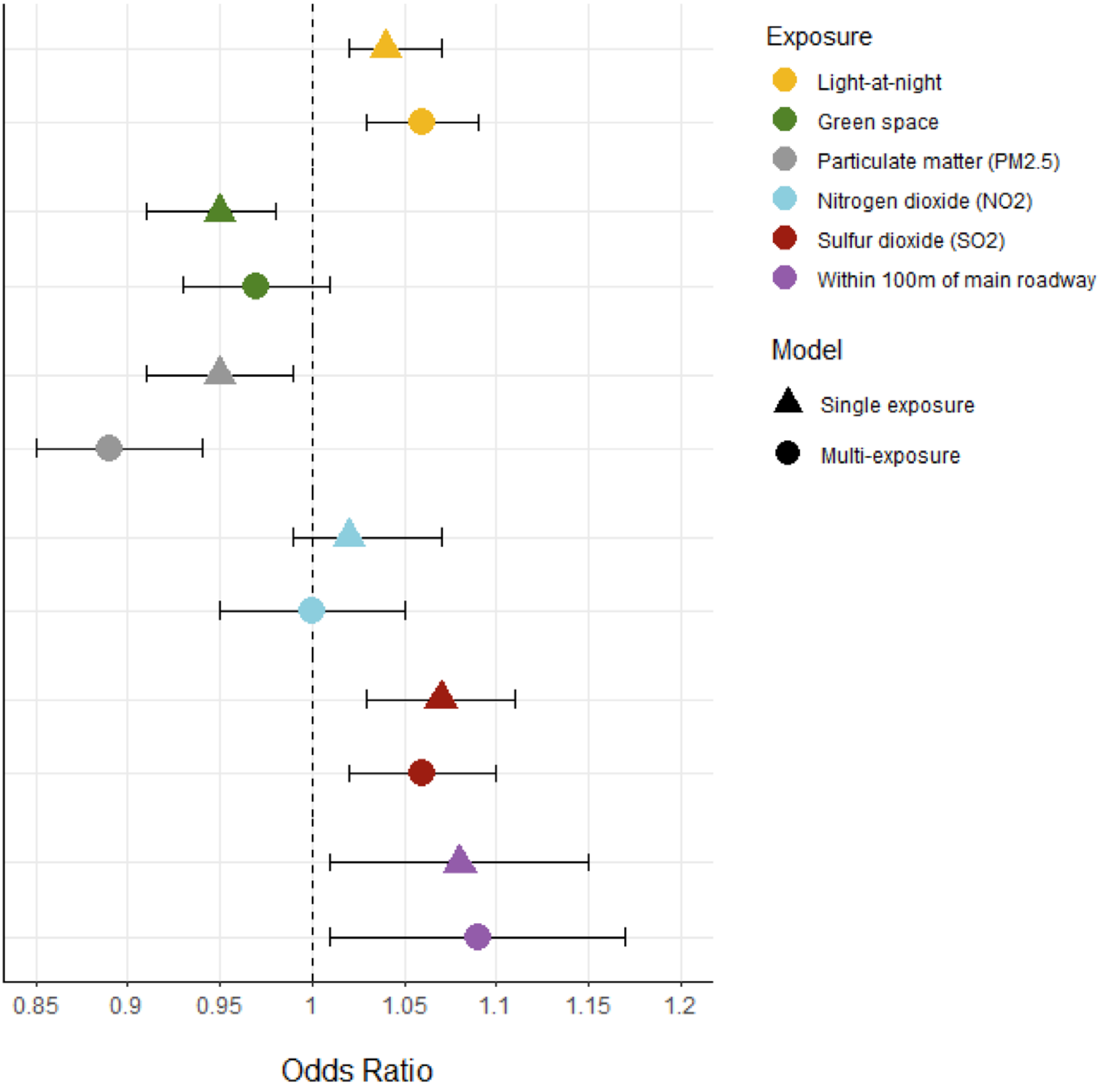

Figure 2. Results of single and multiexposure analysis assessing associations with insufficient sleep. Odds ratios are adjusted for age and sex in both single-exposure and multiexposure models and presented for each interquartile range increase in exposure, except for road proximity, which was assessed as a binary variable. Multiexposure models included all factors shown in the figure.

were found to be at a 9% increased odds of reporting insufficient sleep as compared with those living ≥100 m from a main roadway (OR = 1.09; 95% CI = 1.02, 1.17). As seen in Table 3, the only statistically significant interactions were observed for SO_2 and income (*P* = 0.01) and SO_2 and urbanicity (*P* = 0.03), where the greater odds of insufficient sleep in association with SO_2 exposure seemed to be restricted to those participants with lower incomes (OR = 1.15) versus higher incomes (OR = 1.03) and those participants living in more urban areas (OR = 1.11) versus less urban areas (OR = 1.02).

No strong correlations between the various built environment factors were observed (Figure 1). Correlations ranged from *r* = −0.3 (LAN and greenness) to 0.6 (NO_2 and LAN). Multiexposure analysis was restricted to the 27,451 participants with complete data on age, sex, sleep duration, and all built environment factors. As seen in Figure 2, effect estimates for those factors found to be statistically significantly associated with sleep duration in single exposure analyses were largely unchanged in the multiexposure analysis.

Discussion

We observed evidence of independent associations between multiple built environment factors and sleep duration. Though the specific measures utilized between the studies differed, our findings for LAN and greenness are consistent with those from a recent large-scale evaluation in the California Teachers Study, which included 51,562 women, and is one of the only other studies, to date, that has considered exposure to multiple built environment factors.[21] However, unlike the California Teachers Study, we did not observe compelling evidence of associations between $PM_{2.5}$ and sleep duration. This may be attributable to the lower levels of exposure observed in our study population; in the BCGP, the mean $PM_{2.5}$ level was 5.6 μg/m³, while in the

California Teachers Study it was 10.4 μg/m^3. We did, however, observe a significant association between SO_2 and insufficient sleep, an association that has not been previously evaluated. In stratified analyses, this association was largely restricted to those with lower household incomes and those living in more urban areas. Urban areas did have higher SO_2 levels compared with less urban areas (0.4 vs. 0.2 ppb), but no similar difference by household income was seen (0.4 ppb for both income groups). There is need for more research into the impacts of air pollution on sleep health that is not just limited to sleep disordered breathing and that carefully considers the role of social disparities.

The mechanism by which LAN negatively impacts sleep, namely circadian disruption through suppression of melatonin secretion,[5] is well understood. Greenness has been observed to have multiple benefits to general health, including enhanced mental health and reduced stress, through which improvements to sleep may occur.[12,13] A negative affect of SO_2 on sleep duration may be attributable to sleep-related respiratory issues caused by SO_2 exposures,[20] though levels of exposure in our cohort were quite low (mean = 0.4 ppb). It is possible that SO_2 measures acted as a proxy for some other exposure; SO_2 is generally associated with industrial activities and emissions from vehicles and equipment that burn high sulphur-containing fuels (e.g., large ships).

We did not have data on noise exposure, which the California Teachers Study found to be significantly associated with reduced sleep duration.[21] The association between roadway proximity and sleep duration may be attributed to roadway proximity acting as a proxy for traffic-related noise exposure.[6] Roadway proximity may also be capturing exposures to unmeasured air pollution constituents such as ultrafine particles, volatile organic compounds, and particle-bound polycyclic aromatic hydrocarbons, which are typically elevated near major roadways[37] and could have independent effects on sleep duration. Though sex is a predictor of sleep,[38,39] we did not observe significant differential effects of built environment factors on sleep duration by sex. Only a few previous studies have evaluated differential effects of outdoor LAN exposure by sex/gender on sleep, and findings were mixed.[7,10,40] One study evaluated sex-specific effects of greenness on sleep and found that reduced greenness was particularly detrimental to sleep among men.[15] More research into sex-specific effects on these associations is needed.

Our study had multiple strengths, including a relatively large sample size with data on multiple built environment factors and detailed data on demographic and lifestyle factors to adjust for potential confounding effects. Limitations included the use of a cross-sectional study design and reliance on self-reported sleep duration, which tends to overestimate more objectives measures of sleep.[41,42] However, use of gold-standard methods to measure sleep (e.g., polysomnography or actigraphy) in large study populations, like ours, remains impractical. We also did not have data to assess other important dimensions of sleep, including sleep latency, sleep efficiency, and wake time after sleep onset.[43] Another limitation was the lack of data to determine the amount of outdoor air pollution entering homes and contributions to exposure from indoor sources of air pollution. Similarly, we lacked data on the amount of outdoor LAN getting into home environments and data on indoor sources of LAN exposure such as electronic devices.[44] A previous study conducted among children in the Netherlands compared personal measurements of LAN taken within the home to satellite-based measures and found minimal evidence of correlation between the measures.[45] It is possible that the LAN measures in our study were, in fact acting as a proxy for some other aspect of the built environment for which we did not have data. A previous simulation study also demonstrated that studies using low-resolution LAN data, such as the data used in our study, are more prone to bias, including confounding.[46] In future studies, we will look to incorporate higher resolution LAN data.

We observed that increased outdoor LAN, SO_2, and closer proximity to main roadways were independently associated with increased odds of reporting shorter sleep durations, while increased greenness was independently associated with decreased odds of reporting shorter sleep durations. Pending additional research, our results suggest that careful planning of communities may be a strategy for improving sleep duration at the population level. Future research should include longitudinal study designs and evaluations of the mediating effects of insufficient sleep on links between built environment and chronic disease.

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