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Associations between neighbourhood street pattern, neighbourhood socioeconomic status and sleep in adults

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ABSTRACT

Sleep duration is a risk factor for poor health and all-cause mortality. Evidence suggests that neighbourhood characteristics such as built environment and socioeconomic status (SES) may affect sleep duration in adults. This study examined the relationship between neighbourhood built environment (i.e., measured via the street pattern) and SES with sleep duration in adults (n = 797) from 12 neighbourhoods in Calgary (Canada). Covariate adjusted linear and multinomial logistic regression models estimated the associations between street pattern (grid, warped-grid, curvilinear), SES and sleep duration. We also tested if the interaction between street pattern and SES was associated with sleep duration. Although neighbourhood street pattern and neighbourhood SES were not independently associated with sleep, the interaction between street pattern and neighbourhood SES, was associated with mean sleep duration. Individuals living in curvilinear low SES neighbourhoods had the shortest sleep duration (6.93 h per day; 95% CI 6.68, 7.18), while those living in curvilinear high SES neighbourhoods slept the longest (7.43 h per day; 95% CI 7.29, 7.57). Neighbourhood street pattern and SES, as well as their interaction, were not associated with the odds of sleeping shorter or longer than 7 to 8 h per day. Our findings suggest that the combined effect of the neighbourhood built environment and SES is potentially important for influencing sleep duration. More research is needed to understand the complex interrelationships between the built environment, SES, and sleep.

1. Background

Insufficient or excess sleep are both associated with adverse health outcomes including overweight and obesity (Ogilvie and Patel, 2017; Patel and Hu, 2008), type 2 diabetes (Yaggi et al., 2006), depression (Zhai et al., 2015), low quality of life (Magee et al., 2011), and all-cause mortality (Cappuccio et al., 2010). For optimal health, the United States National Sleep Foundation recommends that adults aged 18 to 64 accumulate between 7 and 9 h of sleep per day (Hirshkowitz et al., 2015). Sleep durations within this range are associated with better mental and physical health and higher quality of life (Hirshkowitz et al., 2015). Despite the importance of sleep to overall health, nearly a third of Canadian adults reported sleeping <7 h per night between 2007 and 2013 (Chaput et al., 2017). Similarly, 35.2% of American adults over the age of 18 report sleeping <7 h per night (CDC, 2017). Thus, a significant proportion of the adult population in North America may be at risk of poor health outcomes associated with insufficient sleep duration.

Neighbourhoods incorporate physical and social characteristics that can influence health (Diez Roux and Mair, 2010). Notably, neighbourhoods are important for influencing health behaviours including physical activity (Durand et al., 2011; McCormack and Shiell, 2011), sedentary behaviour (Prince et al., 2017; Owen et al., 2014), diet quality (Caspi et al., 2012), and social interactions (Leyden, 2003; Francis et al., 2014). There is growing interest in the determinants of sleep, including the role of neighbourhood characteristics (Vézina-Im et al., 2017; Hale et al., 2013). Hale et al. (2013) suggest that multiple pathways by which neighbourhood characteristics may be associated with sleep duration. For example, perceived neighbourhood noise, associated with high density of leisure destinations (e.g. bars, clubs, street events) and neighbourhood infrastructure, have been associated with shorter sleep

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duration (Omlin et al., 2011). Moreover, evidence suggests that traffic related noise results in more frequent night time awakenings and delayed sleep onset (Pirrera et al., 2010), while nocturnal aircraft, road and railway noise are associated with disturbed sleep (Basner and McGuire, 2018).

In addition to noise, other built environment characteristics may impact sleep. In an Australian study, Astell-Burt et al. (2013) found greater proximity to greenspace and parks was associated with lower risk of short sleep, possibly due to higher physical activity and better mental health promoted by greenspace access. In a US study, Johnson et al. (2018) found that higher neighbourhood walkability measured by Walk Score® was associated with shorter sleep duration in older adults. It was suggested this relationship may be dependent on noise, given that neighbourhoods with higher walkability and greater destination density may produce more noise (Johnson et al., 2018). In another US study, adults who perceived their neighbourhood environment to have poorer physical qualities (e.g., higher crime, litter, safety from traffic, community maintenance) reported poorer sleep quality (Hale et al., 2013). Positive perceptions of neighbourhood safety have also been associated with less daytime sleepiness among US adults (Johnson et al., 2015). Other aspects of the neighbourhood environment that may impact sleep duration and quality include neighbourhood socioeconomic status (SES). Studies indicate that residents of low SES neighbourhoods report shorter sleep duration (Fang et al., 2015), and more frequent occurrences of insomnia (Riedel et al., 2012). One US study reported a two-fold higher risk of accumulating very short sleep duration (<5 h/night) among participants from low versus high SES neighbourhoods (Fang et al., 2015). However, some study findings suggest no association between neighbourhood SES and sleep duration (Johnson et al., 2015).

Adults residing in low SES neighbourhoods tend to have poorer health than those residing in high SES neighbourhoods (Bosma et al., 2001; Anderson et al., 1997) and this inequality might be due to low SES neighbourhoods often having built characteristics that are less supportive of health (French et al., 2001; Schüle et al., 2017; Moore et al., 2008). The combined effect or interactions between neighbourhood built characteristics and neighbourhood SES has also been associated with health behaviours such as physical activity (Steinmetz-Wood and Kestens, 2015; Adkins et al., 2017) and diet (Black et al., 2014). However, in several of these studies associations between the built environment and health behaviours such as physical activity were of lower magnitude for adults residing in lower SES neighbourhoods (Steinmetz-Wood and Kestens, 2015; Adkins et al., 2017; Koohsari et al., 2017). Despite evidence that neighbourhood characteristics may influence sleep duration in adults, the combined effects of the neighbourhood built environment and neighbourhood SES on sleep duration have yet to be explored. Therefore, the aim of this study was to examine if neighbourhood built environment (i.e., street pattern) and neighbourhood SES were associated with sleep duration, and likelihood of accumulating more or less than levels of sleep needed to accrue health benefits.

2. Methods

2.1. Study design and recruitment

The University of Calgary Conjoint Health Research Ethics Board approved this study (# REB13-0301). This study used data from the Pathways to Health Study, which has been described in detail elsewhere (McCormack et al., 2017; McInerney et al., 2016). The original aim of the Pathways to Health Study was to identify potential pathways by which the neighbourhood environment contributes to weight status of Canadian adults. Briefly, a cross-sectional study was undertaken in April 2014 in Calgary, Alberta, Canada, a large urban centre with a multi-ethnic population of over 1 million people. All neighbourhoods (administrative boundaries) in Calgary built prior to 1980 were stratified based on their street pattern (grid, warped-grid, and curvilinear) and neighbourhood SES (quartiles: high, medium high, medium low, and low), and 12 neighbourhoods were randomly selected from among these. A random sample of 10,500 households from these 12 neighbourhoods were mailed study information with a consent form, which included web-links to two self-administered questionnaires: 1) Physical Activity, Health and Demographic Questionnaire (PAHDQ) and; 2) Canadian Diet History Questionnaire II. Only data from the PAHDQ were used for the current study. One adult per household (≥20 years of age) with the next birthday was invited to participate. Participation was incentivized through a prize draw. Up to two reminder postcards were sent to households. The response rate for the PAHDQ was 10.1% (n = 1023). Of those who participated, 12.5% (n = 128) completed a paper copy of the PAHDQ. Compared to the census population, our sample over represented older adults, higher income households, women, whites, those with a postsecondary education, those married or common law, and those without children (McCormack et al., 2017).

3. Variables

3.1. Neighbourhood variables

Neighbourhood built environment: Neighbourhood street patterns were classified as curvilinear, warped-grid or grid based on a previously applied classification scheme (Sandalack et al., 2013; Sandalack and Nicolai, 2006). Curvilinear neighbourhoods are characterized by large collector roads that distribute into low street connectivity areas featuring curving roads, low land-use mix, and fewer sidewalks. Similar to other North American cities, in Calgary curvilinear neighbourhoods are concentrated on the periphery of the city (e.g., the suburbs) and became more common in the 1970s onwards. Warped grid neighbourhoods proliferated along the core of the city following World War II, and feature crescent shaped roads, fewer sidewalks beside roads, and less connectivity than traditional grid patterns, with most residences built surrounding a central location (e.g. schools, commercial space). By contrast, grid patterned neighbourhoods feature high connectivity, many sidewalks, higher land-use diversity and distinct north–south and east–west linear street segments. Grid neighbourhoods tend to be the oldest and most centrally located neighbourhoods in Calgary (Sandalack and Nicolai, 2006).

Neighbourhood SES: Neighbourhood SES quartiles were estimated using a previously described and valid method (McCormack et al., 2017; McInerney et al., 2016; Pampalon et al., 2014). Briefly, seven variables were used from the 2006 Canadian census that reflect material and social deprivation within census dissemination areas (McCormack et al., 2017; McInerney et al., 2016). The proportion of 25–64-year-olds whose highest educational level was below a high school diploma; proportion of single-parent families; proportion of rented private dwellings; proportion of individuals divorced, separated, or widowed among those ≥15 years of age; proportion of individuals unemployed among those ≥25 years of age; median gross household income; and average value of dwellings, were used to classify neighbourhood SES (Pirrera et al., 2010). We converted the raw value for each of the variables into z-scores that were then summed and divided into quartiles for the sampling frame. For the analysis presented herein, neighbourhoods were collapsed into high and low SES.

3.2. Outcome variable

Participants self-reported their hours and/or minutes of sleep accumulated over an average 24 h period. Single-item measures of sleep duration have been used previously (Astell-Burt et al., 2013; Fang et al., 2015), and are associated with objective measures of sleep duration, albeit moderately (Cespedes et al., 2016; Lauderdale et al., 2008). Two sleep outcome variables, one continuous and one categorical, were examined in this study. For the categorical variable, sleep duration was categorized as <7 h per day, 7 to 8 h per day, and >8 h per day. While the National Sleep Foundation recommends 7 to 9 h of sleep per day,

Table 1
Descriptive statistics for sleep, neighbourhood built environment, neighbourhood socioeconomic status (SES) and sociodemographic characteristics (n = 797).

Variable	Category	N	%	Mean (SD)
Sleep duration per day (hours)				7.3 (1.0)
Sleep duration per day	Less than 7 hours	185	23.2	
	Between 7 and 8 hours	518	65.0	
	More than 8 hours	94	11.8	
Neighbourhood street pattern	Curvilinear	247	31.0	
	Warped grid	313	39.3	
	Grid	237	29.7	
Neighbourhood SES	High SES	527	66.1	
	Low SES	270	33.9	
Age (years)				51.4 (13.7)
Sex	Male	296	37.1	
	Female	501	62.9	
Ethnicity	White	703	88.2	
	Non-white	94	11.8	
Marital status	Single/other	181	22.7	
	Married/common-law	616	77.3	
Number of dependents in home under 18 years of age				0.6 (0.9)
Employment activity	Non-sitting main activity	332	41.7	
	Sitting is main activity	465	58.3	
Total hours worked per week				21.0 (17.4)
Highest level of education attained	University postgraduate degree	208	26.1	
	University undergraduate degree	382	47.9	
	College, vocation, or trade	152	19.1	
	High school or less	55	6.9	
Annual gross household income	≥$120 000	376	47.2	
	$0-119 999	309	38.8	
	Don’t know/refuse	112	14.0	
Daily total physical activity in hours				7.9 (3.7)
Residential relocation	Moved in past 12 months	92	11.5	
	Did not move in past 12 months	705	88.5	
Survey type administered	Online	708	88.8	
	Hard-copy	89	11.2	

sleeping >9 h per day was not considered as an outcome due to a very small proportion of the sample exceeding this sleep time (n = 16). However, a referent category of 7–8 h per day has been used in other studies and is associated with lower risk of cardiovascular morbidities, all-cause mortality, and hypertension (Magee et al., 2011; Gangwisch et al., 2006; Heslop et al., 2002).

3.3. Covariates

Self-reported covariates included: age (years); sex (male vs. female); race/ethnicity (white vs. non-white); marital status (single/other vs. married/common-law); number of dependents under 18 years living at home; main employment activity (sitting vs. non-sitting); total hours of work per week; highest level of education attained (university postgraduate degree vs. university undergraduate degree, college/vocational/trades certificate or diploma vs. high school or less); annual gross household income (≥$120 000 vs. $0–119 999 vs. don’t know/refuse); type of survey completed (online vs. hard-copy), daily total physical activity (hours per day), and residential relocation (resided in neighbourhood ≥12 months vs. resided in neighbourhood <12 months).

3.4. Statistical analysis

Cases with complete data for sleep duration, neighbourhood characteristics (street pattern and SES) and covariates were included in the final analysis (n = 797; 77.5% of the original sample). Two sample *t*-tests and chi-square tests of proportion were undertaken to compare included and excluded cases for differences in sleep duration, neighbourhood characteristics and covariates.

Descriptive statistics (means, standard deviation [SD], and frequencies) were estimated for sleep duration and neighbourhood and sociodemographic covariates. The outcome variable of sleep duration met the assumptions of linearity, normality, multicollinearity, and homoscedasticity. Covariate-adjusted linear regression estimated unstandardized beta coefficients (*b*) and 95% confidence intervals (95% CI) for the associations between neighbourhood street pattern and SES with mean sleep duration.

Categorical sleep duration met the assumptions of independence for multinomial logistic regression. Covariate-adjusted multinomial logistic regression estimated the odds ratios (OR) and 95% CIs for the associations between neighbourhood street pattern and SES with short (<7 h per day) or long sleep duration (>8 h per day), compared with sleep durations of 7 to 8 h. In addition to the covariate-adjusted main-effects estimates in the linear and multinomial regression models, statistical (multiplicative) interactions between neighbourhood street pattern and SES were also tested. Marginal mean sleep durations by combined street pattern and SES categories were estimated from regression equations including interaction terms. All associations, including the interaction terms, were considered statistically significant at the $p < 0.05$ level. The estimated intra-class correlation ($p = -0.001$) indicated no clustering of sleep duration by neighbourhood, thus we did not control for clustering within our models. All analyses were performed in STATA 15® (StataCorp LLC, College Station, TX).

4. Results

4.1. Sample characteristics

The sample had a mean age of 51.4 (SD 13.7) years, 62.9% were female, 88.2% were white, and 77.3% were married or in a common-law relationship (Table 1). Additionally, 74.0% of participants had an undergraduate university degree or higher and 47.2% reported a gross annual household income of greater than $120,000. The majority of participants (58.4%) reported mainly sedentary work and the total sample worked a mean of 21.0 (SD 17.5) hours per week. The majority of participants had lived in their current neighbourhood for longer than 12 months (88.3%).

The largest proportion of participants lived in warped-grid neighbourhoods (39.3%), while the proportion of participants living in grid (29.7%) and curvilinear (31.0%) neighbourhoods were relatively similar (Table 1). Nearly two thirds (66.1%) of participants lived in high SES neighbourhoods. The sample breakdown by neighbourhood street pattern and SES was as follows: curvilinear high SES (23.2%) and low SES (7.7%); warped-grid high SES (22.3%) and low SES (16.9%), and; high low SES (20.5%) and low SES (9.3%) (Supplement Table 1). The mean sleep duration was 7.3 (SD 1.0) hours per day and nearly two-thirds (65.0%) reported sleep durations between 7 and 8 h per day.

Compared with the analytic sample, cases excluded due to missing data were significantly older, more likely to be single, had fewer dependents under 18 years living at home, worked fewer hours per week, had lower education, less likely to report or not know their gross household income, less physically active and more likely to complete the survey online ($p < 0.05$; Supplement Table 2).

4.2. Correlates of sleep duration

Adjusting for covariates, neighbourhood street pattern and SES were not associated with mean sleep duration (Table 2). Mean sleep duration was negatively associated with the number of dependents under 18 years living at home ($b = -0.13$; 95% CI −0.21, −0.04) and total hours of work per week ($b = -0.01$; 95% CI −0.01, −0.00). Compared with online respondents, participants who completed a hard-copy of the survey had a longer mean sleep duration ($b = 0.28$; 95% CI 0.06, 0.50).

In the final linear regression model there was a significant

Table 2
Linear regression estimates (*b* and 95% CI) for association between neighbourhood street pattern and neighbourhood socioeconomic status (SES) and mean self-reported hours of sleep per day (n = 797).

Variable	Model 1 b (95%CI)	Model 2 b (95%CI)	Model 3 b (95%CI)
Neighbourhood type			
Curvilinear	REF	REF	REF
Warped Grid	-0.01 (-0.17, 0.16)	0.01 (-0.15, 0.18)	-0.17 (-0.37, 0.04)
Grid	0.07 (-.10, 0.25)	0.09 (-0.09, 0.27)	-0.05 (-0.26, 0.16)
Neighbourhood SES			
High SES	REF	REF	REF
Low SES	-0.06 (-0.21, 0.09)	-0.07 (-0.22, 0.08)	**-0.49 (-0.78, -0.21)***
Age (years)		-0.01 (-0.01, 0.00)	-0.01 (-0.02, 0.00)
Sex			
Male		REF	REF
Female		-0.03 (-0.17, 0.12)	-0.02 (-0.16, 0.13)
Ethnicity			
White		REF	REF
Non-white		-0.13 (-0.35, 0.08)	-0.13 (-0.34, 0.09)
Marital status			
Single/Other		REF	REF
Married/Common-law		0.04 (-0.13, 0.22)	0.05 (-0.12, 0.23)
Dependents in home under age 18 years		**-0.13 (-0.21, -0.04)***	**-0.12 (-0.20, -0.04)***
Employment activity			
Non-sitting main activity		REF	REF
Sitting is main activity		0.03 (-0.12, 0.18)	0.03 (-0.11, 0.18)
Total hours worked per week		**-0.01 (-0.01, -0.00)***	**-0.01 (-0.01, -0.00)***
Highest level of education attained			
University postgraduate degree		REF	REF
University undergraduate degree		-0.14 (-0.30, 0.03)	-0.14 (-0.31, 0.03)
College, vocation, or trade		-0.15 (-0.37, 0.06)	-0.15 (-0.36, 0.06)
High school or less		-0.04 (-0.34, 0.26)	0.02 (-0.21, 0.28)
Annual gross household income			
≥$120 000		REF	REF
$0-119 999		0.03 (-0.14, 0.20)	0.04 (-0.13, 0.21)
Don't know/refuse		-0.05 (-0.27, 0.17)	-0.07 (-0.29, 0.15)
Daily total physical activity		-0.01 (-0.03, 0.01)	-0.01 (-0.03, 0.01)
Residential relocation in past 12 months			
Moved in past 12 months		REF	REF
Did not move in past 12 months		0.07 (-0.15, 0.30)	0.09 (-0.14, 0.31)
Survey type completed			
Online		REF	REF
Hard-copy		**0.28 (0.06, 0.50)***	**0.27 (0.05, 0.49)***
Interaction terms			
Warped grid# Low SES			**0.59 (0.23, 0.95)***
Grid# Low SES			**0.53 (0.14, 0.92)***
Constant	7.33 (7.21, 7.46)	7.81 (7.32, 8.31)	7.86 (7.38, 8.33)

Model 1 adjusted for neighbourhood street pattern and neighbourhood socioeconomic status (SES); Model 2 adjusted for neighbourhood street pattern, neighbourhood SES and all sociodemographic variables, physical activity, residential relocation, and survey type; Model 3 adjusted for all variables in Model 2, and tested for interaction between neighbourhood street pattern and neighbourhood SES; Bold values indicate statistically significant differences, $^*p < 0.05$.

interaction between neighbourhood street pattern and neighbourhood SES associated with sleep ($p < 0.05$). Participants residing in warped-grid low SES neighbourhoods ($b = 0.59$; 95% CI 0.23, 0.95) and grid low SES neighbourhoods ($b = 0.53$; 95% CI 0.14, 0.92) slept longer, compared to those residing in curvilinear low SES neighbourhoods. Marginal means from the final linear model indicated that individuals living in curvilinear low SES neighbourhoods had the lowest marginal mean sleep duration (6.93 h per day; 95% CI 6.68, 7.18) and individuals living in curvilinear high SES neighbourhoods had the highest marginal mean sleep duration (7.43 h per day; 95% CI 7.29, 7.57) (Fig. 1 and Supplement Table 1).

4.3. Correlates of short (<7 h per day) and long (>8 h per day) sleep durations

In adjusted models, neighbourhood street pattern and SES were not associated with odds of short or long sleep durations (Table 3). Total hours of work per week was associated with lower odds of long sleep duration (OR = 0.98; 95% CI 0.96, 1.00). Those that had not moved into their current neighbourhood within the past 12 months had higher odds of long sleep duration (OR = 3.04; 95% CI 1.12, 8.24) compared to those who had recently relocated. College, vocational or trades school education, compared to other levels of educational attainment, was associated with odds of both short (OR = 2.06; 95% CI 1.20, 3.54) and long (OR = 2.52; 95% CI 1.29, 4.94) sleep duration, compared to 7 to 8 h. There was no statically significant ($p > 0.05$) interaction between neighbourhood street pattern and SES in models estimating odds of short and long sleep duration.

5. Discussion

In contrast to previous studies (Johnson et al., 2018; Chum et al., 2015; Hale and Do, 2007), we found no independent association between the neighbourhood built environment, defined using street pattern, and sleep duration. We also found no independent association between neighbourhood SES and sleep duration which appears to be consistent with some previous research (Billings et al., 2020). Notably, we did find the interaction between street patterns and neighbourhood SES was associated with shorter mean sleep duration, a novel finding which has not been reported previously.

We found evidence that the interaction between neighbourhood street pattern and SES is associated with sleep duration. Our findings suggest that warped and grid neighbourhoods may confer protection for sleep behaviour for those residing is low SES neighbourhoods. Given the evidence that low neighbourhood SES is associated with shorter sleep duration and risk of insomnia (Fang et al., 2015; Riedel et al., 2012), residing in grid and warped-grid neighbourhoods characterized by higher walkability, compared to curvilinear neighbourhoods, may mitigate the negative impact of low neighbourhood SES on sleep. However, higher walkability (Walk Score®) and population density have been associated with a higher odds of shorter sleep (≤6 h) adjusting for neighbourhood SES (Johnson et al., 2018). Levels of neighbourhood noise may help explain our finding (Omlin et al., 2011; Pirrera et al., 2010; Basner and McGuire, 2018; Feijoo, 2009). In Calgary, grid and warped-grid neighbourhoods tend to be characterized by higher land-use mix, compared to curvilinear neighbourhoods (Sandalack and Nicolai, 2006). Evidence also suggests that higher land-use mix, such as those in grid or warped-grid neighbourhoods, is associated with odds of shorter sleep duration (Chum et al., 2015), incongruent with our findings. Chum et al. (2015) attributed this lower sleep duration to traffic and noise levels, but did not consider the role of neighbourhood SES. Calgary grid neighbourhoods consist of mature trees which may offer more tree canopy (Sandalack and Nicolai, 2006). Johnson et al. (2018) found a higher percentage of tree canopy and higher sound levels were associated with lower odds of short sleep (<6 h) on weekdays. Low SES neighbourhoods, and in particular those which are curvilinear (less walkable), may be built on less desirable land located near industrial areas, near major roads and highways, which may contribute more noise pollution and therefore disturb sleep (Power, 2012; Rosenlieb et al., 2018; Braubach and Fairburn, 2010).

Another plausible explanation for our findings may be the geographical location of Calgary neighbourhoods. Curvilinear neighbourhoods in Calgary are predominantly located on the periphery of the city (Sandalack and Nicolai, 2006). It is possible that participants from these neighbourhoods experienced longer commute times resulting in less time available for sleeping and lower sleep duration (Basner et al., 2007).Our findings might also relate to the role of neighbourhood in health behaviours and in turn sleep. Prior evidence suggests that a neighbourhood built environment more conducive to walking (McCormack and Shiell, 2011) and high SES (Jacobs et al., 2019) are independently associated with higher levels physical activity. Given that physical activity is associated with sleep (Kredlow et al., 2015), this

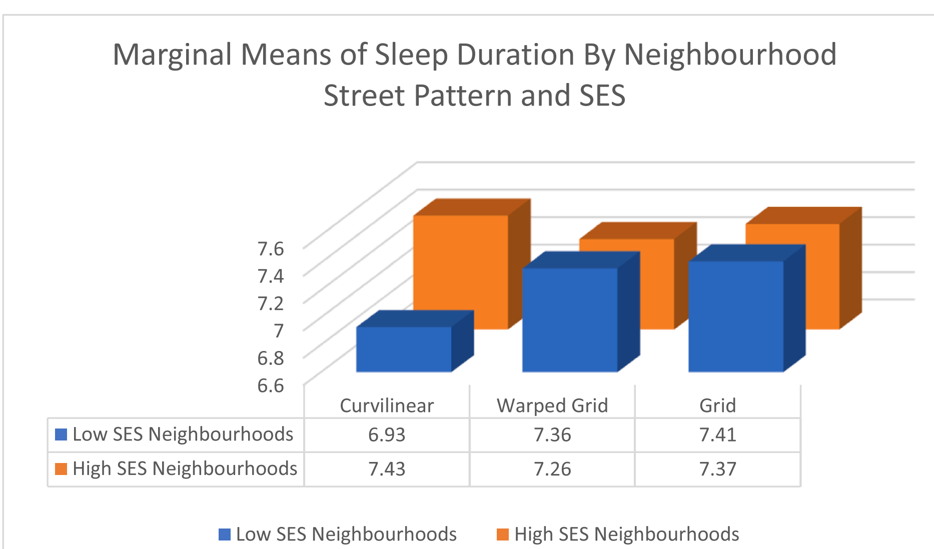

Fig. 1. Fully adjusted estimate of marginal means for sleep duration by neighbourhood street pattern (curvilinear, warped-grid, and grid) and socioeconomic status (SES; high neighbourhood SES, low neighbourhood SES) produced from the linear regression equation testing the interaction between neighbourhood street pattern and SES ($p < 0.05$). Values represent marginal mean sleep duration in hours per day.

Table 3
Multinomial logistic regression estimates (OR and 95% CI) for odds of sleep durations <7 (n = 703) or >8 h (n = 612) compared to 7 to 8 h, per day.

Variable	Below 7 Hours vs. 7 to 8 Hours OR (95%CI)	Above 8 Hours vs. 7 to 8 Hours OR (95%CI)
Neighbourhood type		
Curvilinear	REF	REF
Warped Grid	0.92 (0.60, 1.39)	1.01 (0.57, 1.80)
Grid	0.83 (0.52, 1.31)	1.36 (0.75, 2.47)
Neighbourhood SES		
High SES	REF	REF
Low SES	.38 (0.94, 2.02)	1.43 (0.87, 2.36)
Age (years)	1.01 (0.99, 1.03)	0.99 (0.97, 1.01)
Sex		
Male	REF	REF
Female	0.92 (0.63, 1.33)	0.63 (0.39, 1.02)
Ethnicity		
White	REF	REF
Non-white	1.52 (0.91, 2.54)	0.99 (0.47, 2.08)
Marital status		
Single/Other	REF	REF
Married/Common-Law	1.02 (0.65, 1.59)	1.09 (0.61, 1.95)
Dependents in home under age 18	1.17 (0.96, 1.44)	0.73 (0.52, 1.01)
Employment activity		
Non-sitting main activity	REF	REF
Sitting is main activity	1.04 (0.71, 1.50)	0.85 (0.52, 1.38)
Total hours worked per week	0.99 (0.99, 1.01)	**0.98 (0.96, 1.00)***
Highest level of education attained		
University postgraduate degree	REF	REF
University undergraduate degree	1.53 (0.99, 2.40)	1.20 (0.66, 2.19)
College, vocation, or trade	**2.06 (1.20, 3.54)***	**2.52 (1.29, 4.94)***
High school or less	1.18 (0.53, 2.60)	1.27 (0.48, 3.41)
Annual gross household income		
≥$120 000	REF	REF
$0-119 999	1.17 (0.76, 1.80)	0.96 (0.55, 1.67)
Don't know/refuse	0.99 (0.57, 1.73)	0.75 (0.34, 1.63)
Daily total physical activity	1.05 (1.00, 1.11)	1.01 (0.94, 1.08)
Residential relocation in past 12 months		
Moved in past 12 months	REF	**REF**
Did not move in past 12 months	1.11 (0.63, 1.96)	**3.04 (1.12, 8.24)***
Survey type administered		
Online	REF	REF
Hard-copy	1.07 (0.61, 1.90)	1.69 (0.89, 3.23)

Models are adjusted for neighbourhood street pattern, neighbourhood socioeconomic status (SES), and all sociodemographic variables, physical activity, residential relocation, and survey type. Bold values indicate statistically significant differences, $*p < 0.05$.

offers a possible pathway linking neighbourhood environments to sleep. However, we adjusted for daily total physical activity, thus it appears any relationship between the interaction of neighbourhood street pattern and SES with sleep duration is independent of physical activity. This suggests other pathways may explain our findings. Despite controlling for income and education and neighbourhood tenure, we cannot rule out that some low SES individuals with potentially poorer sleep chose to reside in curvilinear or less walkable neighbourhoods, possible due to lower property values. More walkable neighbourhoods tend to have higher property values (Pivo and Fisher, 2011; Rauterkus and Miller, 2011). Our findings might suggest that tailored environmental (e.g., planting trees or reducing traffic to decrease noise) as well as non-environmental interventions need to target low SES curvilinear neighbourhoods in order to improve sleep among residents.

Congruent with some previous evidence (Billings et al., 2020), we found a lack of association between neighbourhood SES and sleep duration in our sample. Nevertheless, other studies have found that living in a low SES neighbourhood was associated with shorter sleep duration and risk of insomnia (Fang et al., 2015; Riedel et al., 2012) and suggested several pathways to explain this association. Fang et al. (2015) hypothesized that lower neighbourhood SES may impact sleep via exposure to air and/or noise pollution that could increase stress, potentially leading to shorter sleep duration. Riedel et al. (2012) suggested that low-income adults residing in neighbourhoods with high unemployment may be at higher risk of insomnia, due to compounding effects of area and individual-level socioeconomic uncertainty. Other evidence suggests that residents of neighbourhoods with lower SES are more likely to report lower trust in neighbours, higher perceptions of crime, and higher perceptions of disorder (Wilson et al., 2004). These neighbourhood characteristics are also related to lower sleep quality (Hale et al., 2013; Hill et al., 2016) which may contribute to shorter sleep durations. Our findings suggest that these pathways may be mitigated by built environment, presenting potential new avenues for research on the association between neighbourhood characteristics and sleep.

Consistent with previous findings (Chapman et al., 2012; Hagen et al., 2013), a larger number of dependents under 18 year in the home was associated with shorter mean sleep duration. Total hours of work per week was also associated with a relatively lower sleep duration, and lower odds of sleeping longer than 8 h, consistent with other findings suggesting work weeks of longer than 35 h are associated with odds of shorter sleep duration (Hale, 2005). Education in college, vocational or trades was associated with odds of both short and long sleep. Individuals with training in trades or vocational education tend to report shift work employment which itself is related to inconsistent sleep patterns (Åkerstedt, 2003), perhaps explaining this relationship. Notably, a habituation effect could be present amongst those who have lived in their neighbourhood for longer than 12 months, given a nearly 3 times higher odds of sleeping longer than 8 h per day. It is plausible that longer term residents in our study were more accustomed to neighbourhood ambient noise (Omlin et al., 2011), and thus may have experienced less disturbed sleep. The finding that participants who requested a hard-copy of the survey had longer mean sleep duration, may reflect overall screen use in the sample. Given that higher screen time exposure is associated with lower sleep duration (Vallance et al., 2015), it is possible those who completed the online survey had higher overall exposure to screens, increasing their risk of shorter sleep duration compared to those who completed the hard-copy survey.

To our knowledge, our study is the first to test and demonstrate an interaction between the neighbourhood built environment and neighbourhood SES and its association with sleep duration in adults. A strength of this study was our inclusion of objective measures of neighbourhood built environment and SES. Despite our novel findings this study has several limitations. Causal relationships cannot be inferred from this cross-sectional study. Despite demonstrating important associations between the neighbourhood built and SES environments and sleep, the low response rate limits the generalizability of our findings. Further, our single item self-report measure of sleep duration may be prone to overestimation (Cespedes et al., 2016; Lauderdale et al., 2008). Despite using a measure of neighbourhood SES similar to that used in other Canadian research (Johnson et al., 2018), our categorization into low and high SES meant that non-linear associations with sleep duration could not be assessed. Our findings may not generalize to adults residing in the most socioeconomically disadvantaged neighbourhoods. Future studies investigating potential neighbourhood determinants of sleep duration should include comprehensive self-report or objective-measures of sleep duration (i.e., via accelerometers) to obtain more accurate estimates of associations.

6. Conclusion

Our study contributes novel evidence on the role of neighbourhood environments in shaping health. Our findings suggests that the association between low neighbourhood SES and sleep duration may be mitigated through modifying the neighbourhood built environment. While we found the interaction between neighbourhood street pattern and SES to be associated with mean sleep duration, the neighbourhood environment does not seem to support the achievement of recommended levels of sleep. In addition to other commonly investigated health supportive behaviours (e.g., physical activity, weight status, diet, and social interaction), researchers should increasingly focus on the role of neighbourhoods in shaping sleep duration. Novel evidence of a significant interaction between neighbourhood street pattern and SES that is associated with sleep duration suggests that testing for interactive effects may be crucial in understanding complex neighbourhood determinants of sleep duration in adult populations.

Author contributions

RL, DLO, and GRM conceived and designed the study. RL undertook the data analysis. All authors interpreted the results and drafted the manuscript. All authors approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2021.101345.

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