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 Shiel, 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 (Vezina-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.
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). Despite evidence that neighbourhood characteristics may influence 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 (Boasma 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 (Sandallack et al., 2013; Sandallack 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 (Sandallack 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,
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 (79.7; 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.

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) | Less than 7 hours | 185 | 23.2 | 7.3 (1.0) |
| 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) | 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 | Non-sitting main activity | 332 | 41.7 |        |
| | Sitting is main activity | 465 | 58.3 |        |
| Total hours worked per week | 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 | 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 |        |
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

| 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 (-0.10, 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                                    | REF               | REF               | REF               |
| Male                                  | -0.03 (-0.17, 0.12) | -0.02 (-0.16, 0.13) |                   |
| Female                                |                   |                   |                   |
| Ethnicity                             |                   |                   |                   |
| White                                 | REF               | REF               | REF               |
| Non-white                             | -0.13 (-0.35, 0.08) | -0.13 (-0.34, 0.09) |                   |
| Marital status                        |                   |                   |                   |
| Single/Other                          | REF               | 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               | 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               | 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               | 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               | 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               | REF               |
| Hard-copy                             | 0.28 (0.06, 0.50)*  | 0.27 (0.05, 0.49)* |                   |
| Interaction terms                     |                   |                   |                   |
| Warped grid# Low SES                  | REF               |                   |                   |
| Grid# Low SES                         |                   |                   |                   |
| Constant                              | 7.33 (7.21, 7.46)  | 7.81 (7.32, 8.31)  | 7.86 (7.36, 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 statistically 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 (Sandlack 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 (Sandlack 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 (Sandlack 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.
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.

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 (0.37, 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.
higher odds of sleeping longer than 8 h per day. It is plausible that longer sleep duration suggests that testing for interactive effects mitigated through modifying the neighbourhood built environment. Our findings suggest that association between low neighbourhood SES and 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 suggest 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.

References

Ogilvie, R.P., Patel, S.R., 2017. The epidemiology of sleep and obesity. Sleep Health 3 (5), 383–388.
Patel, S.R., Hu, F.B., 2008. Short sleep duration and weight gain: a systematic review. Obesity 16 (3), 643–653.
Yaggi, H.K., Arajo, A.B., McKnily, J.B., 2006. Sleep duration as a risk factor for the development of type 2 diabetes. Diabetes Care 29 (3), 657–661.
Zhai, L., Zhang, H., Zhang, D., 2015. Sleep duration and depression among adults: a meta-analysis of prospective studies. Depress Anxiety 32 (9), 664–670.
Magen, C.A., Caputti, P., Ivensen, C.W., 2011. Relationships between self-rated health, quality of life and sleep duration in middle aged and elderly Australians. Sleep Med. 12 (4), 346–350.
Cappuccio, F.P., D’Elia, L., Strazzullo, P., Miller, M.A., 2010. Sleep duration and all-cause mortality: a systematic review and meta-analysis of prospective studies. Sleep 33 (5), 585–592.
Hirshkowitz, M., Whiton, K., Albert, S.M., Alessi, C., Bruni, O., DonCarlos, L., et al., 2015. National Sleep Foundation’s updated sleep duration recommendations. Sleep Health 1 (4), 233–243.
Chaput, J.-P., Wong, S.L., Michaud, I., 2017. Duration and quality of sleep among Canadians aged 18 to 79. Health Rep. 28 (9), 28–33.
CDC, Short Sleep Duration Among US Adults 2017, available from: <https://www.cdc.gov/sleep/data_statistics.html>.
Diez Roux, A.V., Mair, C., 2010. Neighbourhoods and health. Ann. N. Y. Acad. Sci. 1186, 125–145.
Durand, C.P., Andalih, M., Dunton, G.F., Wolch, J., Pentz, M.A., 2011. A systematic review of built environment factors related to physical activity and obesity risk: implications for smart growth urban planning. Obes. Rev. 12 (5), e173–e182.
McCormack, G.R., Shiell, A., 2011. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. Int. J. Behav. Nutr. Phys. Act. 8 (1), 125. https://doi.org/10.1186/1479-5868-8-125.
Prince, S.A., Reed, J.L., McFetridge, C., Tremblay, M.S., Reid, B.D., 2017. Correlates of sedentary behaviour in adults: a systematic review. Obes. Rev. 18 (8), 915–935.
Owen, N., Salmon, L.J., Koehoort, P., Pedder, G., Turrell, G., 2014. Sedentary behaviour and health: mapping environmental and social contexts to underpin chronic disease prevention. Br. J. Sports Med. 48 (3), 174–177.
Caspí, C.E., Sorensen, G., Subramanian, S.V., Kawachi, I., 2012. The local food environment and diet: a systematic review. Health Place 18 (5), 1172–1187.
Leyden, K.M., 2003. Social capital and the built environment: the importance of walkable neighborhoods. Am. J. Public Health 93 (9), 1546–1551.
Francis, J., Giles-Corti, B., Wood, L., Kunin-Murphy, M., 2014. Neighbourhood influences on mental health in master planned estates: a qualitative study of resident perspectives. Health Promot. J. Austr. 25 (3), 186–192.
Vézina-Lim, L.A., Moreno, J.P., Thompson, D., Nicklas, T.A., Baranowski, T., 2017. Individual, social and environmental determinants of sleep among women: protocol for a systematic review and meta-analysis. BMJ Open. 7 (6), e016592. https://doi.org/10.1136/bmjopen-2017-016592.
Hale, L., Hill, T.D., Friedman, E., Javier Nieto, F., Galvao, L.W., Engelman, C.D., Malecki, K.M.C., Peppard, P.E., 2013. Perceived neighborhood quality, sleep quality, and health status: evidence from the Survey of the Health of Wisconsin. Soc. Sci. Med. 79, 17–22.
Omln, S., Brink, M., Bauer, G.F., 2011. Effects of noise on non-traffic-related ambient sources on sleep: review of the literature of 1990–2010. Noise Health 13 (53), 299. https://doi.org/10.4103/1463-1741.62863.
Pirrera, S., De Valck, E., Cloyds, R., 2010. Nocturnal road traffic noise: a review on its assessment and consequences on sleep and health. Environ. Int. 35 (6), 492–498.
Banner, M., McGuire, S., 2018. WHO environmental noise guidelines for the European region: a systematic review on environmental noise and effects on sleep. Int. J. Environ. Res. Public Health 15 (3), 519.
Astell-Burt, T., Feng, X., Kohl, G.S., 2013. Does access to neighbourhood green space promote a healthy duration of sleep? Novel findings from a cross-sectional study of 259 319 Australians. BMJ Open. 3 (8), e003094.
Johnson, D.A., Hirsch, J.A., Moore, K.A., Redline, S., Diez Roux, A., 2018. Associations between the built environment and objective measures of sleep: The Multi-Ethnic Study of Atherosclerosis. Am. J. Epidemiol. 187 (5), 941–950.
