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Article

Does sleep grow on trees? A longitudinal study to investigate potential prevention of insufficient sleep with different types of urban green space

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ABSTRACT

Introduction: To investigate association between urban green space and prevalent and incident cases of insufficient sleep (<6 h sleep per day).

Methods: This longitudinal study examined the odds of prevalent and incident insufficient sleep in relation to indicators of total green space, tree canopy, open grass and other low-lying vegetation in the Sax Institute's 45 and Up Study (baseline 2006–2009; follow-up 2012–2015). Association between green space within 1.6 km road distances and insufficient sleep among 38,982 participants living in Sydney, Wollongong or Newcastle were analysed using multilevel logistic regressions adjusted for confounding.

Results: Participants with more total green space had lower odds of prevalent insufficient sleep (e.g. ≥30% compared with 0-4% total green space odds ratio (OR) = 0.68, 95% credible interval (95%CI) = 0.53, 0.85). The odds of prevalent insufficient sleep were lower among participants with more tree canopy (e.g. ≥30% compared with 0-9% tree canopy OR = 0.78, 95%CI 0.69, 0.88). The odds of incident insufficient sleep were also lower with more tree canopy (e.g. ≥30% compared with 0-9% tree canopy OR = 0.87, 95%CI = 0.75, 0.99). There were no statistically significant associations between prevalent or incident insufficient sleep with open grass or other low-lying vegetation, nor incident sufficient sleep with total green space.

Conclusions: Prioritising restoration and protection of urban tree canopy may help to promote population-wide prevention of insufficient sleep in middle-to-older aged adults.

Introduction

Insufficient sleep typically defined in the scientific literature as less than 6 h per day is a major public health problem affecting non-trivial percentages of the population (e.g. approximately 12% in Australia according to Adams et al., 2017). Insufficient sleep is associated with elevated risks of workplace injuries (Uehli et al., 2014), road traffic accidents (Connor et al., 2001), noncommunicable diseases (NCDs) (Cappuccio et al., 2010a, 2011), weight gain (Cappuccio et al., 2008; Patel & Hu, 2008) and premature mortality (Cappuccio et al., 2010b). Some of these consequences may be mediated by the effects of insufficient sleep on the immune system (Lange, Dimitrov, & Born, 2010) and glucose metabolism (Spiegel et al., 2009). Person-level characteristics like older age, lower educational attainment, lower income and unemployment are associated with insufficient sleep (Magee, Iverson, & Caputi, 2009), with the negative role of shift work a major concern in particular (Kecklund & Axelsson, 2016). Studies have also reported associations between sleep duration and the characteristics of neighbourhoods, including air pollution, light, and noise (Hale et al., 2019, pp. 77–84; Muzet, 2007; Sygna et al., 2014). In the search for scalable public health interventions for prevention of insufficient sleep, interest in and research into potential environmental determinants of sleep duration is rising (Hunter & Hayden, 2018; Johnson, Billings, & Hale, 2018).

One modifiable environmental exposure that holds potential for prevention of insufficient sleep is green space. Green space, which

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includes street trees, gardens, grass reserves, woodlands, forests and parks (Frumkin et al., 2017), may influence sleep duration through three domain pathways: (i) mitigation; (ii) restoration; and (iii) instoration (Markevych et al., 2017). On mitigation, studies report proximity to green space may help with abatement of air pollution (Abhijith et al., 2017) and noise annoyance (Dzhambov & Dimitrova, 2015). Evidence from sleep research suggests proximity to green space may help improve air quality and provide quieter environments that are likely to be an important, though not a sufficient, condition for optimal sleep duration (Halperin, 2014; Zanobetti et al., 2010). On restoration, many field experiments and epidemiological studies across several decades have reported contact with green space can lead to reduction of stress, restoration of cognitive capacities and protection of mental health (Hartig et al., 2014). Sleep studies point to the likely bi-directional relationship between insufficient sleep and mental ill-health (Alvaro, Roberts, & Harris, 2013). Finally, green spaces may help to build capacities (instoration) by providing preferential settings that motivate engagement in different types of outdoor physical recreation (Kredlow et al., 2015) and by supplying spaces in which communities come together to foster greater cohesion (Jennings & Bamkole, 2019) and reduce the prevalence of loneliness (e.g. Maas et al., 2009). Numerous studies suggest greater physical activity can support healthier sleep duration (Kredlow et al., 2015). Some research has reported loneliness may lower sleep quality, potentially via a stress pathway (McHugh & Lawlor, 2013), though this association may also be bi-directional (Simon & Walker, 2018).

While these interconnected pathways linking green space provision and sleep duration are plausible, there has been surprisingly little quantitative research so far. Some cross-sectional studies have assessed for potential effects of green space on the odds of insufficient sleep (Astell-Burt, Feng, & Kolt, 2013; Chum, O'Campo, & Matheson, 2015; Grigsby-Toussaint et al., 2015; Johnson et al., 2018b). Three of these studies (Astell-Burt et al., 2013; Grigsby-Toussaint et al., 2015; Johnson et al., 2018b) reported supportive evidence whereas the fourth found no convincing evidence of association (Chum et al., 2015). No longitudinal studies have been conducted. Among the three cross-sectional studies reporting affirmative findings, one found support specifically for benefits from tree canopy (Johnson et al., 2018b). Consideration of different types of green space provision for prevention of insufficient sleep is under-researched. Yet this is a highly policy-relevant issue, as urban and landscape planners seek evidence on which types of green space offer the strongest overall health gains and health economists aim to determine which types of green space are the most cost-effective to invest in for prevention of NCDs.

Accordingly, the purpose of our study was to advance the emerging scientific evidence linking green space and sleep duration in two important ways. First, we investigated the potential benefits of total green space provision on the odds of prevalent and incident cases of insufficient sleep. Second, we explored which types of green space may be key to these associations (if any).

Method

Four samples of participants were extracted from the Sax Institute's 45 and Up Study (45 and Up Study Collaborators, 2008) with intent to analyse odds of prevalent and incident insufficient sleep in January 2019. Participants (n = 267,153) in the 45 and Up Study lived in New South Wales (NSW) and had been sampled randomly from the Department of Human Services (formerly Medicare Australia) enrolment database, which provides near complete coverage of the population, and filled in postal surveys at baseline (2006–2009) and follow-up (2012–2015). The baseline response rate was approximately 18%, which is low but relative risks from the 45 and Up Study have been shown to be comparable to those drawn from a representative population health survey (Mealing et al., 2010). Participants provided consent for follow-up, of which 147,000 responded. Participants aged ≥80 were oversampled. The sample was restricted to people living in the cities of Sydney, Wollongong or Newcastle at baseline (n = 110,223). This was further restricted to 38,982 participants that completed the follow-up survey and remained in the same local communities over time, as defined by Statistical Area 2s units containing 10,000 residents on average each.

Sleep was measured at baseline and follow-up with the question: *"About how many hours in each 24 h day do you usually spend sleeping (including at night and naps)?"* Insufficient sleep was defined as <6 h sleep. The reference group was 6–10 h sleep using complete-outcome baseline sample of 38,982 participants. Participants who reported >10 h sleep were omitted from the sample, as correlations have been found previously between long sleeps and poor health, which may be attributable to reverse causation (Stamatakis & Punjabi, 2007). Among participants with non-affirmative baseline responses, a second binary outcome was derived based upon incidence of insufficient sleeps at follow-up in a complete-outcome sample of 31,961 participants, respectively.

Each of the two samples were linked to data on percentage green space availability within a 1.6 km (1 mile) network distance buffer around the centroid of each Mesh Block of residence. The Mesh Block is the smallest geographical scale available in Australia at typically 30 to 60 dwellings each. The 1.6 km network distance buffer was selected based upon published guidance (National Prevention Council, 2014). Four green space indicators were derived: (i) total green space; (ii) tree canopy; (iii) open grass without tree canopy; (iv) other low-lying vegetation. Green space data was sourced from Pitney Bowes Ltd in the form of a raster layer ('Geovision') in 2016. This data consisted of a 2-m raster surface classified into descriptive classes captured using machine learning and image classification processes across satellite imagery (8-band multispectral imagery captured by DigitalGlobe's Worldview 3 satellite). Tree canopy included street trees and trees in parks (both deciduous and evergreen). Open grass included herbaceous areas. Open grass and low-lying vegetation were likely under-estimated in areas where they were beneath tree canopy. All four green space indicators were formatted as intervals in order to examine for potentially policy-relevant threshold effects. For total green space and open grass, these intervals were: 0–4%; 5–9%; 10–19%; 20–29%; ≥30%. For tree canopy and other low-lying vegetation, the intervals were slightly different due to small numbers (tree canopy = 0–9%; 10–19%; 20–29%; ≥30%, low-lying vegetation = 0–1%; 2–4%; ≥5%). These categories were based around existing green space standards, for example, the allocation of 10% of subdivisible land to some form of green open space in Perth, Western Australia.

Multilevel logistic regressions estimated with Markov Chain Monte Carlo (MCMC) method (Browne, 2005; Rasbash et al., 2000) took into account clustering of participants within areas. Initial regressions assessed prevalence and incidence of insufficient sleep in relation to each green space indicator, adjusting for age and gender, followed by adjustment for social and economic markers of confounding associated with sleep duration and may also structure access to green space: annual household income; economic status (e.g. employed, retired); educational qualification; and couple status. Each of these markers of potential confounding were self-reported within the 45 and Up Study questionnaire. Weights were not used to address over-sampling of people aged 85 and older.

Results

The prevalence of insufficient sleep at baseline was 18.0% (Table 1). Incidence of insufficient sleep was 13.2%. Comparing participants with ≥30% to those with 0–4% total green space, prevalent and incident insufficient sleep were down by 7.4% and 1.6%, respectively. For participants with ≥30% tree canopy compared with 0–9% tree canopy, prevalent and incident insufficient sleep were 7.50% and 3.76% lower, respectively. Prevalent and incident insufficient sleep were 2.7% and

Table 1
Descriptive statistics of the study sample.

	Total N (baseline)	% insufficient sleep prevalence	Total N (follow-up)	% insufficient sleep incidence
Total	38982	18.0	31961	13.2
Total green space				
0–4%	631	23.3	484	14.1
5–9%	9350	18.7	7599	13.3
10–19%	10400	18.7	8455	13.8
20–29%	10491	18.0	8602	13.1
≥30%	8110	15.9	6821	12.5
Chi-square (p-value)	43.2	<0.001	6.6	0.161
Tree canopy				
0–9%	4051	22.8	3131	15.4
10–19%	15086	19.3	12172	14.0
20–29%	9827	16.8	8172	12.9
≥30%	10015	15.3	8486	11.6
Chi-square (p-value)	139.7	<0.001	37.9	<0.001
Open grass				
0–4%	4818	16.5	4022	12.0
5–9%	16344	16.8	13600	12.4
10–19%	9996	18.9	8112	13.9
20–29%	6161	20.7	4883	14.8
≥30%	1663	19.2	1344	15.0
Chi-square (p-value)	61.2	<0.001	30.1	<0.001
Low-lying vegetation				
0–4%	25051	17.8	20583	13.0
5–9%	12639	18.4	10317	13.5
≥10%	1292	17.9	1061	14.8
Chi-square (p-value)	1.7	0.438	3.8	0.1
Age group				
45-54y	13695	16.4	11370	14.0
55-64y	14301	17.7	11769	12.6
65-74y	7105	18.8	5770	13.0
≥75y	3881	21.4	3052	13.7
Chi-square (p-value)	43.2	<0.001	10.3	0.016
Gender				
Male	18008	18.2	14732	12.4
Female	20974	17.9	17229	13.9
Chi-square (p-value)	0.7	0.389	16.2	<0.001
Annual household income ($)				
0-20k	4095	24.6	3086	16.1
21-30k	2458	20.0	1967	13.2
31-40k	2505	17.3	2072	14.5
41-50k	2663	18.0	2183	14.7
51-70k	4541	18.4	3706	12.6
>70k	15693	15.3	13295	11.4
Not determined	7027	19.6	5652	15.3
Chi-square (p-value)	220.4	<0.001	92.5	<0.001
Education				
None	2238	27.5	1622	18.6
School	6394	20.8	5067	15.8
High School	3684	18.3	3010	14.2
Trade	3271	20.5	2602	14.4
Certificate or Diploma	8694	17.1	7206	12.6
University	14363	15.1	12189	11.3
Missing	338	21.6	265	15.5
Chi-square (p-value)	271.2	<0.001	119.3	<0.001

Table 1 (*continued*)

	Total N (baseline)	% insufficient sleep prevalence	Total N (follow-up)	% insufficient sleep incidence
Total	38982	18.0	31961	13.2
Economic status				
Employed	23410	17.8	19242	12.9
Retired	12467	17.8	10245	13.1
Unemployed	510	24.9	383	18.5
Unpaid work	541	16.1	454	14.1
Disabled	385	30.1	269	21.2
Homemaker	1232	16.6	1028	15.4
Other	437	22.2	340	17.4
Chi-square (p-value)	64.0	<0.001	36.2	<0.001
Couple status				
Not in a couple	8391	23.2	6433	13.9
In a couple	30611	16.6	25528	13.0
Chi-square (p-value)	19.8	<0.001	3.1	0.076

3.1% higher among participants with ≥30% open grass compared with 0–4% open grass nearby, respectively. There was no pattern of prevalent or incident insufficient sleep discernible with respect to low-lying vegetation, so this exposure was not analysed any further.

Fully-adjusted odds ratios for each outcome in relation to total green space, tree canopy and open grass exposures are illustrated in Fig. 1. Participants in total green space intervals higher than 0–4% had lower odds of prevalent short sleep (Fig. 1A). For example, the odds ratio (OR) for participants with 5–9% total green space was 0.76 (95% credible interval (95%CI) = 0.61, 0.95). Although the odds of incident insufficient sleep appeared to be lower at higher intervals of total green space, these associations were not statistically significant (e.g. ≥30% compared with 0–4% OR = 0.90, 95%CI = 0.67, 1.16).

The odds of prevalent insufficient sleep were lower among participants with tree canopy levels at every interval above 0–9% (e.g. ≥30% OR = 0.78, 95%CI 0.69, 0.88, Fig. 1B). The odds of incident insufficient sleep were also lower with more tree canopy, albeit only statistically significantly at the ≥30% level (OR = 0.87, 95%CI = 0.75, 0.99). In contrast to the descriptive analyses, there was no statistically significant evidence of association between prevalent or incident insufficient sleep and the open grass exposure after adjusting for demographic and socioeconomic markers of confounding (Fig. 1C).

Discussion

Our study has enhanced this new area of research in two ways. Lower prevalent insufficient sleep among people with higher total green space available was confirmed. But when examining the data longitudinally, the correlation between total green space and incident insufficient sleep was not convincing. Lower odds of insufficient sleep were more consistently observed among people living near more tree canopy in both the cross-sectional and longitudinal tests. Neither open grass nor other low-lying vegetation were statistically significantly associated with prevalent or incident insufficient sleeps. This suggests urban greening strategies that prioritise increasing the availability of, and reducing inequalities in tree canopy coverage may help to support population-wide improvements in sleep.

Some merits of our study include longitudinal lagged-effects design of the best green space data available and a large residentially stable sample to prevent bias from reverse causation through health-selective migration. Assessment of incident insufficient sleep in this study provided a more robust test of association with green space provision than had previously been achieved, with earlier work relying upon data of cross-sectional design (Astell-Burt et al., 2013; Chum et al., 2015;

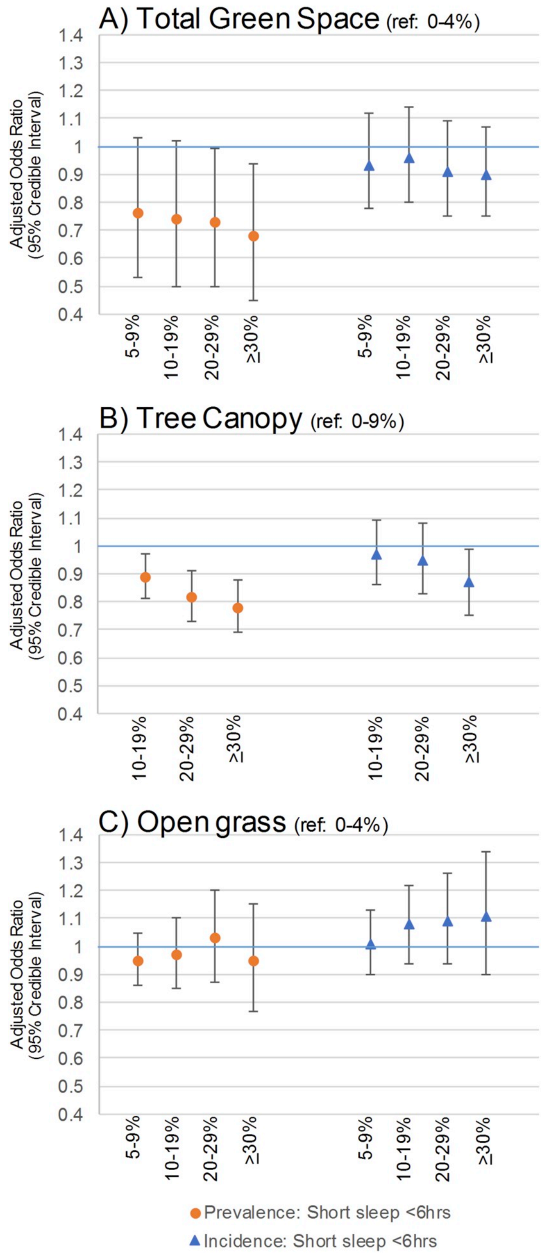

Fig. 1. Odds of prevalent and incident short sleep durations in association with total (A) urban green space, (B) tree canopy, and (C) open grass: multilevel logistic regressions adjusted for confounding and estimated using Markov Chain Monte Carlo method. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Grigsby-Toussaint et al., 2015; Johnson et al., 2018b). This longitudinal design combined with the ability to differentiate between different types of green space afforded the identification of tree canopy, rather than any green space, as being associated with lower odds of incident insufficient sleep.

Limitations include self-report sleep duration data and restriction to an ≥45y population. Our results cannot be generalised to people aged ≤44y. However, the prevalence of insufficient sleep increases with age according to a recent nationally representative survey (Adams et al., 2017), which helps to explain why the prevalence of insufficient sleep in our study (18%) was above the national average for adults ≥18y (12%). Potential underestimation in green space land-use, due to loss of provision in some areas over time could not be measured with the data available. Existing evidence suggests 35% of council areas in Australia have experienced some form of tree canopy loss while only 4% increased tree canopy coverage (Amati et al., 2017). The potential impacts on sleep duration of a change in local tree canopy cover and land-use over time is an important avenue for future research. It is also important to note that our data were limited in respect of open grass cover and other low-lying vegetation being under-estimated in areas where it was located underneath tree canopy.

The identification of tree canopy, rather than any green space *per se,* as potentially important for promoting healthier sleep duration may point towards mitigation and restoration as possible pathways, perhaps via exposure to increased biodiversity (Fuller et al., 2007), natural soundscapes (Annerstedt et al., 2013), amelioration of heat islands (Ng et al., 2012), less psychological distress (Astell-Burt & Feng, 2019) and satisfying human preferences for natural settings with more complex vegetation (Harris et al., 2018). The lack of association between sleep and open grass after adjusting for confounding factors may suggest that pathways involving physical activity are less important in this particular case. However, the association between physical activity and open grass may be contingent upon whether those areas are in private ownership (i.e. back gardens) or are publically accessible (e.g. parks and some sports ovals). Furthermore, research that examines potential pathways using relevant statistical models capable of discerning between serial and parallel mediation would be a prudent next step, as would replication studies and estimates of cost-effectiveness of potential investments in tree canopy. In conclusion, this is the first longitudinal study internationally to link residential green space and sleep duration, with the evidence pointing towards restoration and conservation of urban tree canopy specifically as a scalable public health intervention for prevention of insufficient sleep.

Ethical statements

The University of New South Wales HREC approved the 45 and Up Study and ethics approval for the analyses in this paper was awarded by the University of Wollongong HREC.

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