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Does access to neighborhood green space promote a healthy duration of sleep? Novel findings from 259,319 Australians

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Does access to neighborhood green space promote a healthy duration of sleep? Novel findings from 259,319 Australians

ABSTRACT

Objectives: Experiments demonstrate that exposure to parks and other 'green spaces' promote favorable psychological and physiological outcomes. As a consequence, people who reside in greener neighborhoods may also have a lower risk of short sleep duration (<6 hours). This is potentially important as short sleep duration is a correlate of obesity, chronic disease, and mortality, but so far this hypothesis has not been previously investigated.

Design: Cross-sectional data analysis

Setting: New South Wales, Australia

Participants: This study investigated whether neighborhood green space was associated with a healthier duration of sleep (to the nearest hour) among 259,319 Australians who completed the 45 and Up Study baseline questionnaire between 2006 and 2009 inclusive.

Primary and secondary outcome measures: Multinomial logit regression was used to investigate the influence of an objective measure of green space on categories of sleep duration: 8 hours (normal); between 9 and 10 hours (mid-long sleep); over 10 hours (long sleep); between 6 and 7 hours (mid-short sleep); less than 6 hours (short sleep). Models were adjusted for psychological distress, physical activity, and a range of demographic and socioeconomic characteristics.

Results: People living in greener neighborhoods reported a lower risk of short sleep. For example, compared to participants living in areas with 20% green space land-use, the relative risk ratios for participants with 80%+ green space was 0.86 (95% confidence interval (95%CI) 0.81, 0.92) for durations between 6 and 7 hours, and 0.68 (95%CI 0.57, 0.80) for less than 6-hours sleep. Unexpectedly, the benefit of more green space for achieving 8 hours of sleep was not explained by controls for psychological distress, physical activity, or other socioeconomic factors.

Conclusion: Green space planning policies may have wider public health benefits than previously recognized. Further research on the role of green space in promoting healthier sleep durations and patterns is warranted.

Article Summary

Article Focus

- Previous work suggests that more green space within the neighborhood environment can promote better mental health and more active lifestyles
- Better mental health and more active lifestyles are correlates of a healthy duration of sleep (usually around 8 hours a night)
- Greener neighborhoods, therefore, may guard against short sleep duration (usually less than 6 hours per night), which is correlated with obesity, chronic disease, and mortality

Key Messages

- In a large study of Australian adults, we found those in greener neighborhoods were at a lower risk of short sleep (< 6 hours a night)
- More green space was not associated with longer sleep durations (which are also correlated with poor health outcomes)
- Unexpectedly, the benefit of more green space for achieving a healthier duration of sleep was not explained by controls for psychological distress, physical activity, and socioeconomic variables

Strengths and Limitations

- This study benefits from a large sample size focusing on adults in middle-to-older age, who simultaneously shoulder the vast burden of chronic disease and are the biggest users of health services
- This study is strengthened by use of validated measures of sleep duration, psychological distress, physical activity, and an objective measure of green space exposure
- Cross-sectional data prohibits causal inference, though follow up of the participants across time will allow the opportunity for replication of this study with a longitudinal design

Introduction

Positive psychological and physiological outcomes from exposure to parks and other forms of natural environment in experimental studies [1-3] have fuelled support for the integration of these 'green spaces' within planning policy.[4 5] Health benefits are thought to accrue via psycho-neuro-endocrine pathways, wherein the experience of nature triggers restoration.[6-8] These benefits are likely to be in tandem with physical activity, more of which is not only correlated with better mental health,[9] but also increasingly likely among people who live in greener neighborhoods.[10 11]

While the epidemiological literature is increasingly replete with studies documenting association between green spaces, mental health and physical activity, less attention has been paid to other important health behaviors and outcomes. One such outcome is sleep duration. Many studies have reported a parabolic association[12] between the number of hours a person sleeps and their subsequent risk of poor self-rated health [13], obesity [14 15], cardiovascular disease [16], diabetes [17 18] and death.[19-21] Favorable mental health and active lifestyles are thought to be drivers of a healthier duration of sleep (usually around 8 hours per night).[22-24] Since these drivers are widely reported to be positive outcomes of living in greener neighborhoods, we hypothesized that people with access to more green space would therefore be more likely to achieve a healthier duration of sleep.

This hypothesis was investigated in a large sample of Australian adults in middle-to-older age, who simultaneously shoulder the vast burden of chronic disease and are the biggest users of healthcare in Australia.

METHOD

Data

A sample of 259,319 participants with valid data on sleep duration were selected from 267,151 in the 45 and Up Study.[25] The questionnaire is available online from www.45andup.org.au. Participants were randomly selected from the Medicare Australia database (the national provider of universal

health insurance) and surveyed between 2006 and 2009. The survey response rate was 18%, though previous work has shown that results from the 45 and Up Study are comparable to those derived from a representative population survey.[26] Geocoding of participants in the 45 and Up Study was available at the Census Collection Districts (CCD) scale. CCDs contain 225 people on average and were the smallest geography at which 2006 Census data were disseminated.[27] The University of New South Wales Human Research Ethics Committee approved The 45 and Up Study.

Outcome measure

Sleep duration was derived from responses to the following question: *"About how many hours in each 24 hour day do you usually spend sleeping (including at night and naps)?"* and has been used in previous analyses of the same data.[13 14 24 28] Responses to this question were missing for 7,755 people and these were omitted from the analyses. To account for the curvilinear association between sleep duration and health,[12] responses were classified into a multinomial variable as follows: 8 hours (normal); between 9 and 10 hours (mid-long sleep); over 10 hours (long sleep); between 6 and 7 hours (mid-short sleep); less than 6 hours (short sleep). This classification allows for the healthiest duration (8 hours) to be used as a reference group for all other categories.

Green space

Meshblocks classified as 'parkland' in the Australian Bureau of Statistics (ABS) land-use classification for 2006 were used to construct the measure of green space. 'Farmland' meshblocks were not used as they do not strictly represent spaces available for recreation. The measure of green space was based upon the percentage available within a 1 kilometer (km) buffer around the population-weighted centroid of each CCD. A 1km buffer was selected so as to represent land-use within a reasonable walking distance from home. The percentage green space measure was classified into fifths to explore for potential non-linearities (0-20%, 20-40%, 40-60%, 60-80%, 80%+).

Other individual and neighborhood measures

The Kessler Psychological Distress Scale (K10) was used to assess mental health status.[29 30] The K10 measures symptoms of psychological distress experienced over the past four weeks, including feeling tired for no reason, nervous, hopeless, restless, depressed, sad and worthless. Participants had five choices for each of the ten questions (none of the time =1, a little of the time =2, some of the time =3, most of the time =4, all of the time=5). The K10 is constructed by summing responses to each of the questions, with scores of 22 and over identified those with a high risk of psychological distress.[31] The K10 has been used in this way in previous published analyses of the 45 and Up Study.[32]

The measure of physical activity was an aggregate of the number of 10 minute sessions spent either walking or in moderate to vigorous physical activity (MVPA), assessed using the Active Australia Survey.[33] The question was "How many times did you do each of these activities last week?" Participants could indicate walking, moderate (e.g. gentle swimming) and vigorous (e.g. jogging) forms activity separately.

A range of other individual characteristics were also taken account of, including age, gender, ethnicity, country of birth, body mass index (BMI), annual income, highest educational qualifications, economic status (employed, unemployed, retired, inactive due to poor health), couple status, number of alcoholic drinks consumed in the last week, smoking status, language other than English spoken at home, and the Duke Social Support Index.[34]

Two other characteristics at the neighborhood-level were considered. The Socio-Economic Index for Areas (SEIFA) 'Index of Relative Socio-Economic Advantage/Disadvantage' was used to measure local socioeconomic circumstances. Differences between urban and rural areas were controlled using the 'Accessibility / Remoteness Index of Australia' (ARIA). Like the measure of green space, both of these neighborhood indicators were created using data from 2006 to fit with the baseline questionnaire.

Statistical analysis

Cross-tabulations were used to compare the patterning of each sleep duration category according to proximity to green space and all other explanatory variables. A multinomial logit regression was used assess the risk of short sleep versus an 8-hour sleep duration (reference), accounting for longer sleeps as separate categories simultaneously within the same model. Parameters were exponentiated to relative risk ratios (RRR). RRRs over 1 indicated positive association, whereas RRRs below 1 denoted negative association. Bivariate models containing the measure of green space (fitted as a categorical variable) were initially adjusted for interactions between age and gender. The robustness of any associations found were then tested with controls for psychological distress and physical activity. Socioeconomic and other explanatory variables were then added sequentially, with any change in the potential association between green space exposure and sleep duration documented. To account for the nested data structure, the Huber-White method was utilized in all models to adjust standard errors.[35 36] The log-likelihood ratio test ($p<0.05$) was used to identify statistically significant associations. Analyses were conducted in STATA 12 (StataCorp, TX, USA).

RESULTS

In Table 1 the prevalence of sleep for 8 hour duration (adjusted for age and gender) was demonstrably higher in neighborhoods with a higher percentage of green space. This was also for sleep durations between 9 and 10 hours, but not for those of 10 hours or more. Meanwhile, the prevalence of sleep durations less than 8 hours was higher in neighborhoods with less green space. The percentage point difference reported between neighborhoods with 80%+ and less than 20% green space proximity was 3.6 for a mid-short sleep duration between 6 and 7 hours ($p<0.001$). A smaller, though statistically significant gap was also reported for short sleeps less than 6 hours (0.9 percentage points, $p<0.001$). The risk of short sleep duration (6 hours or less per day) was 4 times higher among participants at high risk of psychological distress (95%CI 3.8, 4.3), 1.5 times higher among obese people versus

those normal BMI (95%CI 1.46, 1.63), 1.8 times higher among people earning less than $20,000 a year (95%CI 1.7, 1.9), 1.6 times higher for residents of the most deprived quintile of neighborhoods (95%CI 1.5, 1.7) and 1.1 times higher for those in remote and rural versus urban areas (95%CI 1.0, 1.2).

Preliminary multinomial logit regression took a bivariate format with green space as the sole predictor of sleep duration. The 259,319 participants were nested within 11,719 CCDs. Compared to participants reporting 8 hour sleep as the base category, the risk of shorter sleep durations was lower for those with access to more green space. For example, the Relative Risk Ratios (RRRs) for participants with 80%+ versus less than 20% green space was 0.86 (95%CI 0.81, 0.92) for durations between 6 and 7 hours, and 0.68 (95%CI 0.57, 0.80) for less than 6 hours sleep. In contrast, there was no association between neighborhood green space and the risk of longer sleep durations between 9 and 10 hours (RRR 1.06, 95%CI 0.99, 1.14), or over 10 hours (RRR 0.85, 95%CI 0.70, 1.03).

These results appeared to corroborate our hypothesis. However, this was founded on the basis that greener neighborhoods stimulate mental health and more active lifestyles, which would then promote a healthier duration of sleep. Ergo, we expected that the association between green space and sleep duration would be explained by controls for mental health and physical activity. Adding the K10 variable showed participants at a high risk of psychological distress were more likely to report sleeps of less and also more than 8 hours in duration ($p<0.001$). Conversely, adding physical activity to the model did not result in a significant association with sleep duration. Unexpectedly, and counter to our hypothesis, adjusting for these variables had negligible impact on the association between green space and sleep duration.

The final step was to interrogate the consistency of the green space parameters against other factors shown to be associated with short and long sleep duration. These variables were added sequentially to the previous model, with Figure 1 illustrating the results of the final multinomial logit regression. Many characteristics of individuals were associated with sleep duration in line with previous work, such as unemployment and sleeps of less than 6 hours (RRR 1.20, 95%CI 1.02, 1.32) and more than

10 hours (RRR 3.17, 95%CI 2.66, 3.78). Participants in more affluent and geographically remote neighborhoods were also at a lower risk of short and long sleep durations (p<0.001). Controlling for all of these variables did attenuate the negative association between green space and short sleep duration, but not fully. For participants with access to 80%+ green space within their neighborhood compared to those with less than 20%, the RRR of sleeping between 6 and 7 hours was 0.92 (95%CI 0.87, 0.98) and 0.81 (95%CI: 0.69, 0.96) for sleeps of less than 6 hours in duration. There remained no association between green space exposure and sleeps of more than 8 hours.

DISCUSSION

As countries invest in large scale green space planning policies,[4 5] it would be prudent to ask whether parks and other forms of natural environment have any other health benefits aside from those which are already widely reported (namely, better mental health and increased physical activity). This study has demonstrated that people who live in greener environs are more likely to achieve a healthier duration of sleep. The protective effect of green space was isolated to guarding against the risk of short sleep (less than 8 hours), with no association found for longer sleeps. These results were consistent after controlling for factors already known to be associated with short and long sleep and, surprisingly, were not explained by indicators of mental health and physical activity. The significance of these findings are put in context when one considers that sleep durations of less than 6 hours are consistently associated with many of the major chronic health conditions[14-18] that threaten the sustainability of health systems.[37 38] As such, these results suggest that large-scale investments in green space policy could have a wider public health benefit than has been previously acknowledged.

Restoration from access to nature can occur directly [1], although exposure to green space is undoubtedly entwined, to a potentially large extent, with active lifestyles for which parks and other public open spaces are attractive environments for participation [39]. This makes the finding that green space was associated with a healthier duration of sleep, irrespective of psychological distress or participation in physical activity, more intriguing. One possible explanation is that the physical

activity variable measures participation, but not with any specific reference to the place in which it occurs. Participants scoring higher on the physical activity variable therefore do not necessarily perform those activities in the green spaces where they live and this interaction between behavior and environment may be important to control.[40] Another plausible mechanism is the dispersal of traffic density [41] and noise pollution in areas with more green space, which could otherwise have a detrimental influence on sleep duration.[42 43] No measure of traffic density or noise pollution was available for this study however. Thus, while more green space appears to be protective against a short duration of sleep, it is not yet clear whether this is demonstrably because of a direct effect on restoration that is not picked up by the K10, or if it operates via other structural processes operating at the neighborhood level. Further research on the spatial patterning of sleep duration that accounts for other structural variables, such as noise pollution, is warranted to isolate the potentially causal mechanism(s) at play.

This study benefited from a large sample size and an objective measure of green space. However, the focus on a population of 45 years and older limits the generalisability to younger people, for whom further studies are advised. The survey response rate was 18%, though previous work has shown that results from the 45 and Up Study are comparable to those from a representative survey [26]. While the cross-sectional design limits prospects for causal inference, such inferences might not be achieved with longitudinal data either, as contemporaneous exposure to green space, rather than one that is temporally lagged may be what counts most for determining sleep duration. Longitudinal studies would nevertheless be useful for testing hypotheses related to temporal effects. It is plausible that sleep duration varies across the week and during the day (e.g. naps), particularly between weekdays and weekends, but the measure of sleep available in the 45 and Up Study was generalist and could not facilitate these more detailed enquiries. Similarly, the Active Australia Survey is a measure of overall physical activity, but did not afford a distinction between leisure and other types (e.g. active travel). Finally, not all green spaces are the same and those of subjectively higher quality may be more important for determining health outcomes [44], including sleep duration.

Ethics: The University of New South Wales Human Research Ethics Committee approved The 45 and Up Study. Local ethical approval for this study was awarded by the University of Western Sydney.

Funding: No funding was sought for this study.

Data sharing: Data from the 45 and Up Study is only accessible via a data licence issued through blinded peer-review. It is not available for sharing with parties who do not possess an approved Agreement with the Data Custodian.

Competing Interests: None

Contributorship: Conceived and designed the experiments: TAB XF GK

Performed the experiments: TAB XF.

Analyzed the data: TAB XF.

Wrote the paper: TAB XF GK

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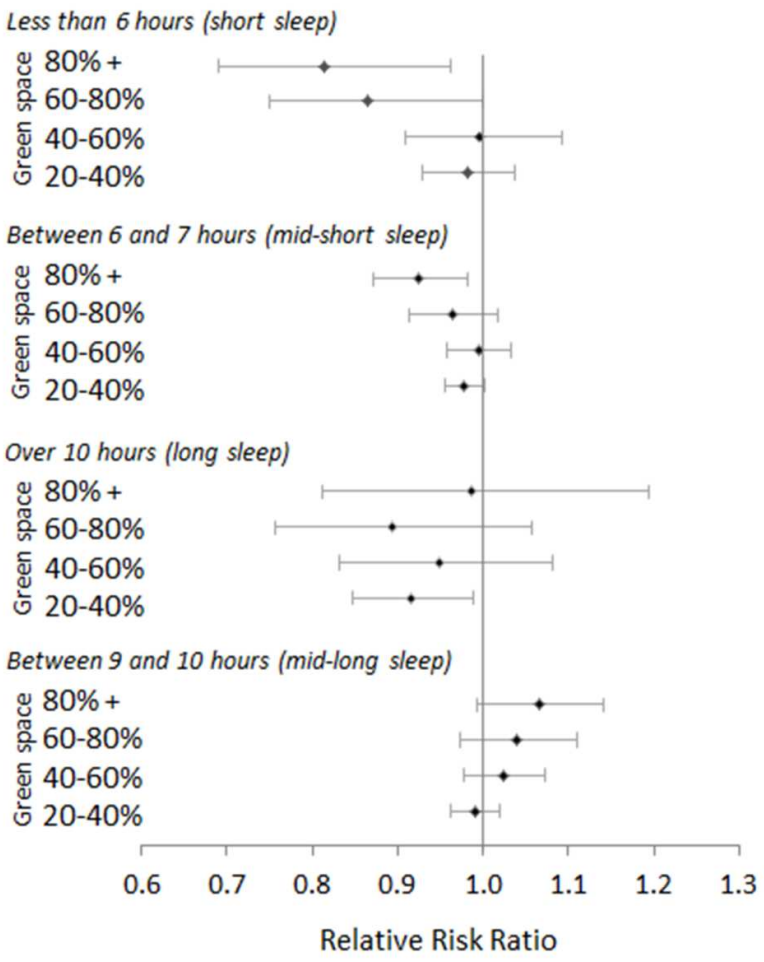
Table 1: Age-gender adjusted patterning of sleep duration by proximity to green space

	8 hours (normal)	Between 9 and 10 hours (mid-long sleep)	Over 10 hours (long sleep)	Between 6 and 7 hours (mid-short sleep)	Less than 6 hours (short sleep)
N (259,319)	104,432	47,424	4,938	92,860	9,665
Green space % (n)	% (95% Confidence Interval)				
0-20% (177,106)	40.0 (39.8, 40.3)	17.5 (17.3, 17.7)	1.6 (1.5, 1.6)	35.6 (35.3, 35.8)	3.7 (3.6, 3.8)
20-40% (49,316)	40.4 (39.9, 40.8)	16.9 (16.6, 17.3)**	1.4 (1.3, 1.5)***	36.2 (35.7, 36.7)*	3.6 (3.4, 3.8)
40-60% (18,045)	40.5 (39.7, 41.3)	17.9 (17.3, 18.6)	1.4 (1.2, 1.6)*	35.3 (34.4, 36.1)	3.3 (3.1, 3.6)**
60-80% (8,253)	41.2 (40.0, 42.3)*	18.6 (17.6, 19.6)**	1.3 (1.1, 1.5)	34.4 (33.2, 35.7)*	2.9 (2.5, 3.3)***
80% + (6,599)	41.9 (40.7, 43.2)**	20.1 (19.1, 21.2)***	1.6 (1.3, 1.9)	32.0 (30.8, 33.2)***	2.8 (2.3, 3.2)***

*** p < 0.001; ** p < 0.01; * p < 0.05 (from 0-20% green space as the reference group)

Figure 1: Association between proximity to green space and duration of sleep (fully adjusted)



*reference group = less than 20% green space

** multinomial logit regression with robust standard errors and base category comprising participants reporting 8 hours sleep duration. Models were adjusted for: age; gender; Kessler scale of psychological distress; physical activity (measured by the Active Australia survey); weight status; couple status; ethnicity; country of birth; annual household income; highest qualifications; economic status; language spoken at home; number of alcoholic drinks consumed per week; smoking status; social support; the Socio-Economic Index for Areas (SEIFA) 'Index of Relative Socio-Economic Advantage/Disadvantage'; and the 'Accessibility/Remoteness Index of Australia' (ARIA).

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ABSTRACT

Objectives: Experiments demonstrate that exposure to parks and other 'green spaces' promote favorable psychological and physiological outcomes. As a consequence, people who reside in greener neighborhoods may also have a lower risk of short sleep duration (<6 hours). This is potentially important as short sleep duration is a correlate of obesity, chronic disease, and mortality, but so far this hypothesis has not been previously investigated.

Design: Cross-sectional data analysis

Setting: New South Wales, Australia

Participants: This study investigated whether neighborhood green space was associated with a healthier duration of sleep (to the nearest hour) among 259,319 Australians who completed the 45 and Up Study baseline questionnaire between 2006 and 2009 inclusive.

Primary and secondary outcome measures: Multinomial logit regression was used to investigate the influence of an objective measure of green space on categories of sleep duration: 8 hours (normal); between 9 and 10 hours (mid-long sleep); over 10 hours (long sleep); between 6 and 7 hours (mid-short sleep); less than 6 hours (short sleep). Models were adjusted for psychological distress, physical activity, and a range of demographic and socioeconomic characteristics.

Results: People living in greener neighborhoods reported a lower risk of short sleep. For example, compared to participants living in areas with 20% green space land-use, the relative risk ratios for participants with 80%+ green space was 0.86 (95% confidence interval (95%CI) 0.81, 0.92) for durations between 6 and 7 hours, and 0.68 (95%CI 0.57, 0.80) for less than 6-hours sleep. Unexpectedly, the benefit of more green space for achieving 8 hours of sleep was not explained by controls for psychological distress, physical activity, or other socioeconomic factors.

Conclusion: Green space planning policies may have wider public health benefits than previously recognized. Further research on the role of green space in promoting healthier sleep durations and patterns is warranted.

Ethics: The University of New South Wales Human Research Ethics Committee approved The 45 and Up Study. Local ethical approval for this study was awarded by the University of Western Sydney.

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Article Focus

- Previous work suggests that more green space within the neighborhood environment can promote better mental health and more active lifestyles
- Better mental health and more active lifestyles are correlates of a healthy duration of sleep (usually around 8 hours a night)
- Greener neighborhoods, therefore, may guard against short sleep duration (usually less than 6 hours per night), which is correlated with obesity, chronic disease, and mortality

Key Messages

- In a large study of Australian adults, we found those in greener neighborhoods were at a lower risk of short sleep (< 6 hours a night)
- More green space was not associated with longer sleep durations (which are also correlated with poor health outcomes)
- Unexpectedly, the benefit of more green space for achieving a healthier duration of sleep was not explained by controls for psychological distress, physical activity, and socioeconomic variables

Strengths and Limitations

- This study benefits from a large sample size focusing on adults in middle-to-older age, who simultaneously shoulder the vast burden of chronic disease and are the biggest users of health services
- This study is strengthened by use of validated measures of sleep duration, psychological distress, physical activity, and an objective measure of green space exposure
- Cross-sectional data prohibits causal inference, though follow up of the participants across time will allow the opportunity for replication of this study with a longitudinal design

Introduction

Positive psychological and physiological outcomes from exposure to parks and other forms of natural environment in experimental studies [1-3] have fuelled support for the integration of these 'green spaces' within planning policy.[4 5] Health benefits are thought to accrue via psycho-neuro-endocrine pathways, wherein the experience of nature triggers restoration.[6-8] These benefits are likely to be in tandem with physical activity, more of which is not only correlated with better mental health,[9] but also increasingly likely among people who live in greener neighborhoods.[10-12]

While the epidemiological literature is increasingly replete with studies documenting association between green spaces, mental health and physical activity, less attention has been paid to other important health behaviors and outcomes. One such outcome is sleep duration. Many studies have reported a parabolic association[13] between the number of hours a person sleeps and their subsequent risk of poor self-rated health [14], obesity [15 16], cardiovascular disease [17], diabetes [18 19] and death.[20-22] Favorable mental health and active lifestyles are thought to be drivers of a healthier duration of sleep (usually around 8 hours per night).[23-25] Since these drivers are widely reported to be positive outcomes of living in greener neighborhoods, we hypothesized that people with access to more green space would therefore be more likely to achieve a healthier duration of sleep.

This hypothesis was investigated in a large sample of Australian adults in middle-to-older age, who simultaneously shoulder the vast burden of chronic disease and are the biggest users of healthcare in Australia.

METHOD

Data

A sample of 259,319 participants with valid data on sleep duration were selected from 267,151 in the 45 and Up Study.[26] The questionnaire is available online from www.45andup.org.au. Participants were randomly selected from the Medicare Australia database (the national provider of universal

health insurance) and surveyed between 2006 and 2009. The survey response rate was 18%, though previous work has shown that results from the 45 and Up Study are comparable to those derived from a representative population survey.[27] Geocoding of participants in the 45 and Up Study was available at the Census Collection Districts (CCD) scale. CCDs contain 225 people on average and were the smallest geography at which 2006 Census data were disseminated.[28] The University of New South Wales Human Research Ethics Committee approved The 45 and Up Study.

Outcome measure

Sleep duration was derived from responses to the following question: *"About how many hours in each 24 hour day do you usually spend sleeping (including at night and naps)?"* and has been used in previous analyses of the same data.[14 15 25 29] Responses to this question were missing for 7,755 people and these were omitted from the analyses. To account for the curvilinear association between sleep duration and health,[13] responses were classified into a multinomial variable as follows: 8 hours (normal); between 9 and 10 hours (mid-long sleep); over 10 hours (long sleep); between 6 and 7 hours (mid-short sleep); less than 6 hours (short sleep). This classification allows for the healthiest duration (8 hours) to be used as a reference group for all other categories.

Green space

Meshblocks classified as 'parkland' in the Australian Bureau of Statistics (ABS) land-use classification for 2006 were used to construct the measure of green space. 'Farmland' meshblocks were not used as they do not strictly represent spaces available for recreation. The measure of green space was based upon the percentage available within a 1 kilometer (km) buffer around the population-weighted centroid of each CCD. A 1km buffer was selected so as to represent land-use within a reasonable walking distance from place of residence, and has been used in previous studies of

green space and health.[11 12 30 31] The percentage green space measure was classified into fifths to explore for potential non-linearities (0-20%, 20-40%, 40-60%, 60-80%, 80%+).

Other individual and neighborhood measures

The Kessler Psychological Distress Scale (K10) was used to assess mental health status.[32 33] The K10 measures symptoms of psychological distress experienced over the past four weeks, including feeling tired for no reason, nervous, hopeless, restless, depressed, sad and worthless. Participants had five choices for each of the ten questions (none of the time =1, a little of the time =2, some of the time =3, most of the time =4, all of the time=5). The K10 is constructed by summing responses to each of the questions, with scores of 22 and over identified those with a high risk of psychological distress.[34] The K10 has been used in this way in previous published analyses of the 45 and Up Study.[35]

The measure of physical activity was an aggregate of the number of 10 minute sessions spent either walking or in moderate to vigorous physical activity (MVPA), assessed using the Active Australia Survey.[36] The question was "How many times did you do each of these activities last week?" Participants could indicate walking, moderate (e.g. gentle swimming) and vigorous (e.g. jogging) forms activity separately.

A range of other individual characteristics were also taken account of, including age, gender, ethnicity, country of birth, body mass index (BMI), annual income, highest educational qualifications, economic status (employed, unemployed, retired, inactive due to poor health), couple status, number of alcoholic drinks consumed in the last week, smoking status, language other than English spoken at home, and the Duke Social Support Index.[37]

Two other characteristics at the neighborhood-level were considered. The Socio-Economic Index for Areas (SEIFA) 'Index of Relative Socio-Economic Advantage/Disadvantage' was used to measure local socioeconomic circumstances. Differences between urban and rural areas were controlled using

the 'Accessibility / Remoteness Index of Australia' (ARIA). Like the measure of green space, both of these neighborhood indicators were created using data from 2006 to fit with the baseline questionnaire.

Statistical analysis

Cross-tabulations were used to compare the patterning of each sleep duration category according to proximity to green space and all other explanatory variables. A multinomial logit regression was used assess the risk of short sleep versus an 8-hour sleep duration (reference), accounting for longer sleeps as separate categories simultaneously within the same model. Parameters were exponentiated to relative risk ratios (RRR). RRRs over 1 indicated positive association, whereas RRRs below 1 denoted negative association. Bivariate models containing the measure of green space (fitted as a categorical variable) were initially adjusted for interactions between age and gender. The robustness of any associations found were then tested with controls for psychological distress and physical activity. Socioeconomic and other explanatory variables were then added sequentially, with any change in the potential association between green space exposure and sleep duration documented. To account for the nested data structure, the Huber-White method was utilized in all models to adjust standard errors.[38 39] The log-likelihood ratio test ($p<0.05$) was used to identify statistically significant associations. Analyses were conducted in STATA 12 (StataCorp, College Station, TX, USA).

RESULTS

In Table 1 the prevalence of sleep for 8 hour duration (adjusted for age and gender) was demonstrably higher in neighborhoods with a higher percentage of green space. This was also for sleep durations between 9 and 10 hours, but not for those of 10 hours or more. Meanwhile, the prevalence of sleep durations less than 8 hours was higher in neighborhoods with less green space. The percentage point difference reported between neighborhoods with 80%+ and less than 20% green space proximity was

3.6 for a mid-short sleep duration between 6 and 7 hours (p<0.001). A smaller, though statistically significant gap was also reported for short sleeps less than 6 hours (0.9 percentage points, p<0.001). The risk of short sleep duration (6 hours or less per day) was 4 times higher among participants at high risk of psychological distress (95%CI 3.8, 4.3), 1.5 times higher among obese people versus those normal BMI (95%CI 1.46, 1.63), 1.8 times higher among people earning less than $20,000 a year (95%CI 1.7, 1.9), 1.6 times higher for residents of the most deprived quintile of neighborhoods (95%CI 1.5, 1.7) and 1.1 times higher for those in remote and rural versus urban areas (95%CI 1.0, 1.2).

Preliminary multinomial logit regression took a bivariate format with green space as the sole predictor of sleep duration. The 259,319 participants were nested within 11,719 CCDs. Compared to participants reporting 8 hour sleep as the base category, the risk of shorter sleep durations was lower for those with access to more green space. For example, the Relative Risk Ratios (RRRs) for participants with 80%+ versus less than 20% green space was 0.86 (95%CI 0.81, 0.92) for durations between 6 and 7 hours, and 0.68 (95%CI 0.57, 0.80) for less than 6 hours sleep. In contrast, there was no association between neighborhood green space and the risk of longer sleep durations between 9 and 10 hours (RRR 1.06, 95%CI 0.99, 1.14), or over 10 hours (RRR 0.85, 95%CI 0.70, 1.03).

These results appeared to corroborate our hypothesis. However, this was founded on the basis that greener neighborhoods stimulate mental health and more active lifestyles, which would then promote a healthier duration of sleep. Ergo, we expected that the association between green space and sleep duration would be explained by controls for mental health and physical activity. Adding the K10 variable showed participants at a high risk of psychological distress were more likely to report sleeps of less and also more than 8 hours in duration (p<0.001). Conversely, adding physical activity to the model did not result in a significant association with sleep duration. Unexpectedly, and counter to our hypothesis, adjusting for these variables had negligible impact on the association between green space and sleep duration.

The final step was to interrogate the consistency of the green space parameters against other factors shown to be associated with short and long sleep duration. These variables were added sequentially to the previous model, with Figure 1 illustrating the results of the final multinomial logit regression. Many characteristics of individuals were associated with sleep duration in line with previous work, such as unemployment and sleeps of less than 6 hours (RRR 1.20, 95%CI 1.02, 1.32) and more than 10 hours (RRR 3.17, 95%CI 2.66, 3.78). Participants in more affluent and geographically remote neighborhoods were also at a lower risk of short and long sleep durations (p<0.001). Controlling for all of these variables did attenuate the negative association between green space and short sleep duration, but not fully. For participants with access to 80%+ green space within their neighborhood compared to those with less than 20%, the RRR of sleeping between 6 and 7 hours was 0.92 (95%CI 0.87, 0.98) and 0.81 (95%CI: 0.69, 0.96) for sleeps of less than 6 hours in duration. There remained no association between green space exposure and sleeps of more than 8 hours.

DISCUSSION

As countries invest in large scale green space planning policies,[4 5] it would be prudent to ask whether parks and other forms of natural environment have any other health benefits aside from those which are already widely reported (namely, better mental health and increased physical activity). This study has demonstrated that people who live in greener environs are more likely to achieve a healthier duration of sleep. The protective effect of green space was isolated to guarding against the risk of short sleep (less than 8 hours), with no association found for longer sleeps. These results were consistent after controlling for factors already known to be associated with short and long sleep and, surprisingly, were not explained by indicators of mental health and physical activity. The significance of these findings are put in context when one considers that sleep durations of less than 6 hours are consistently associated with many of the major chronic health conditions[15-19] that threaten the sustainability of health systems.[40 41] As such, these results suggest that large-scale investments in green space policy could have a wider public health benefit than has been previously acknowledged.

Restoration from access to nature can occur directly [1], although exposure to green space is undoubtedly entwined, to a potentially large extent, with active lifestyles for which parks and other public open spaces are attractive environments for participation [42]. This makes the finding that green space was associated with a healthier duration of sleep, irrespective of psychological distress or participation in physical activity, more intriguing. One possible explanation is that the physical activity variable measures participation, but not with any specific reference to the place in which it occurs. Participants scoring higher on the physical activity variable therefore do not necessarily perform those activities in the green spaces where they live and this interaction between behavior and environment may be important to control.[43] Another plausible mechanism is the dispersal of traffic density [44] and noise pollution in areas with more green space, which could otherwise have a detrimental influence on sleep duration.[45 46] No measure of traffic density or noise pollution was available for this study however. Thus, while more green space appears to be protective against a short duration of sleep, it is not yet clear whether this is demonstrably because of a direct effect on restoration that is not picked up by the K10, or if it operates via other structural processes operating at the neighborhood level. Further research on the spatial patterning of sleep duration that accounts for other structural variables, such as noise pollution, is warranted to isolate the potentially causal mechanism(s) at play.

This study benefited from a large sample size and an objective measure of green space. However, the focus on a population of 45 years and older limits the generalisability to younger people, for whom further studies are advised. The survey response rate was 18%, though previous work has shown that results from the 45 and Up Study are comparable to those from a representative survey [27]. While the cross-sectional design limits prospects for causal inference, such inferences might not be achieved with longitudinal data either, as contemporaneous exposure to green space, rather than one that is temporally lagged may be what counts most for determining sleep duration. Longitudinal studies would nevertheless be useful for testing hypotheses related to temporal effects. It is plausible that sleep duration varies across the week and during the day (e.g. naps), particularly between weekdays and weekends, but the measure of sleep available in the 45 and Up Study was generalist and could not

facilitate these more detailed enquiries. Similarly, the Active Australia Survey is a measure of overall physical activity, but did not afford a distinction between leisure and other types (e.g. active travel). Finally, while previous work has shown that different measures of green space yield similar associations with health outcomes,[47] we recognize that not all green spaces are the same and future work should explore whether variation in subjective quality[48] or type[49] (e.g. parks versus conservation areas) results in systematic differences in health outcomes, including sleep duration.

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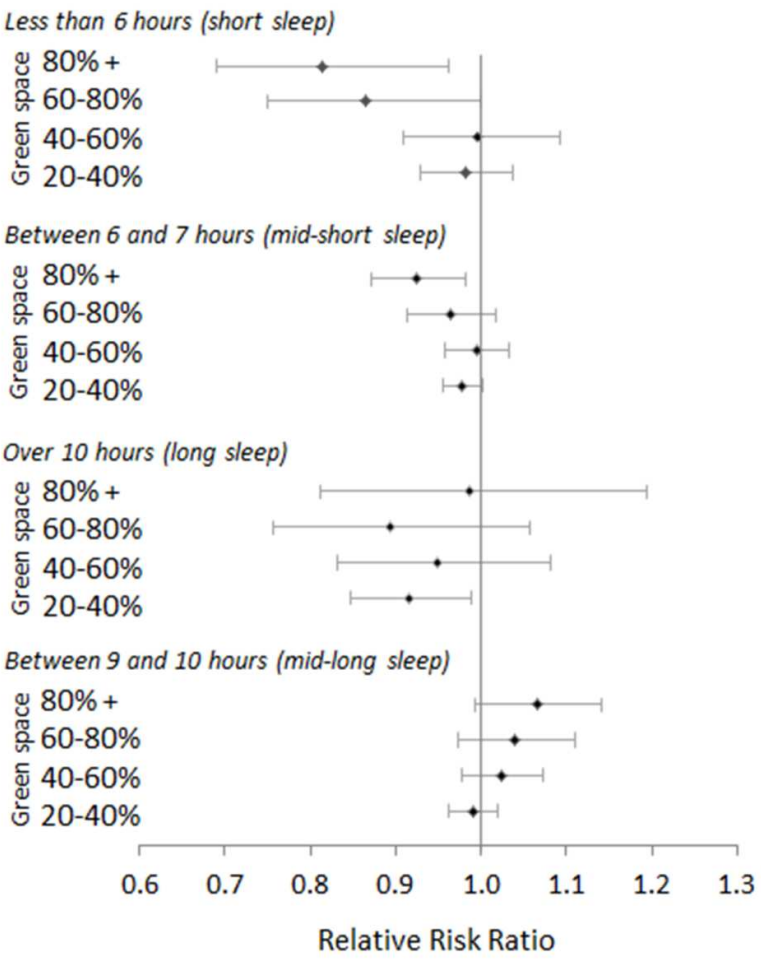
Table 1: Age-gender adjusted patterning of sleep duration by proximity to green space

	8 hours (normal)	Between 9 and 10 hours (mid-long sleep)	Over 10 hours (long sleep)	Between 6 and 7 hours (mid-short sleep)	Less than 6 hours (short sleep)
N (259,319)	104,432	47,424	4,938	92,860	9,665
Green space % (n)			% (95% Confidence Interval)		
0-20% (177,106)	40.0 (39.8, 40.3)	17.5 (17.3, 17.7)	1.6 (1.5, 1.6)	35.6 (35.3, 35.8)	3.7 (3.6, 3.8)
20-40% (49,316)	40.4 (39.9, 40.8)	16.9 (16.6, 17.3)**	1.4 (1.3, 1.5)***	36.2 (35.7, 36.7)*	3.6 (3.4, 3.8)
40-60% (18,045)	40.5 (39.7, 41.3)	17.9 (17.3, 18.6)	1.4 (1.2, 1.6)*	35.3 (34.4, 36.1)	3.3 (3.1, 3.6)**
60-80% (8,253)	41.2 (40.0, 42.3)*	18.6 (17.6, 19.6)**	1.3 (1.1, 1.5)	34.4 (33.2, 35.7)*	2.9 (2.5, 3.3)***
80% + (6,599)	41.9 (40.7, 43.2)**	20.1 (19.1, 21.2)***	1.6 (1.3, 1.9)	32.0 (30.8, 33.2)***	2.8 (2.3, 3.2)***

*** p < 0.001; ** p < 0.01; * p < 0.05 (from 0-20% green space as the reference group)

Figure 1: Association between proximity to green space and duration of sleep (fully adjusted)



*reference group = less than 20% green space

** multinomial logit regression with robust standard errors and base category comprising participants reporting 8 hours sleep duration. Models were adjusted for: age; gender; Kessler scale of psychological distress; physical activity (measured by the Active Australia survey); weight status; couple status; ethnicity; country of birth; annual household income; highest qualifications; economic status; language spoken at home; number of alcoholic drinks consumed per week; smoking status; social support; the Socio-Economic Index for Areas (SEIFA) 'Index of Relative Socio-Economic Advantage/Disadvantage'; and the 'Accessibility/Remoteness Index of Australia' (ARIA).

Does access to neighborhood green space promote a healthy duration of sleep? Novel findings from 259,319 Australians

ABSTRACT

Objectives: Experiments demonstrate that exposure to parks and other 'green spaces' promote favorable psychological and physiological outcomes. As a consequence, people who reside in greener neighborhoods may also have a lower risk of short sleep duration (<6 hours). This is potentially important as short sleep duration is a correlate of obesity, chronic disease, and mortality, but so far this hypothesis has not been previously investigated.

Design: Cross-sectional data analysis

Setting: New South Wales, Australia

Participants: This study investigated whether neighborhood green space was associated with a healthier duration of sleep (to the nearest hour) among 259,319 Australians who completed the 45 and Up Study baseline questionnaire between 2006 and 2009 inclusive.

Primary and secondary outcome measures: Multinomial logit regression was used to investigate the influence of an objective measure of green space on categories of sleep duration: 8 hours (normal); between 9 and 10 hours (mid-long sleep); over 10 hours (long sleep); between 6 and 7 hours (mid-short sleep); less than 6 hours (short sleep). Models were adjusted for psychological distress, physical activity, and a range of demographic and socioeconomic characteristics.

Results: People living in greener neighborhoods reported a lower risk of short sleep. For example, compared to participants living in areas with 20% green space land-use, the relative risk ratios for participants with 80%+ green space was 0.86 (95% confidence interval (95%CI) 0.81, 0.92) for durations between 6 and 7 hours, and 0.68 (95%CI 0.57, 0.80) for less than 6-hours sleep. Unexpectedly, the benefit of more green space for achieving 8 hours of sleep was not explained by controls for psychological distress, physical activity, or other socioeconomic factors.

Conclusion: Green space planning policies may have wider public health benefits than previously recognized. Further research on the role of green space in promoting healthier sleep durations and patterns is warranted.

Ethics: The University of New South Wales Human Research Ethics Committee approved The 45 and Up Study. Local ethical approval for this study was awarded by the University of Western Sydney.

Funding: No funding was sought for this study.

Data sharing: Data from the 45 and Up Study is only accessible via a data license issued through blinded peer-review. It is not available for sharing with parties who do not possess an approved Agreement with the Data Custodian.

Article Focus

- Previous work suggests that more green space within the neighborhood environment can promote better mental health and more active lifestyles
- Better mental health and more active lifestyles are correlates of a healthy duration of sleep (usually around 8 hours a night)
- Greener neighborhoods, therefore, may guard against short sleep duration (usually less than 6 hours per night), which is correlated with obesity, chronic disease, and mortality

Key Messages

- In a large study of Australian adults, we found those in greener neighborhoods were at a lower risk of short sleep (< 6 hours a night)
- More green space was not associated with longer sleep durations (which are also correlated with poor health outcomes)
- Unexpectedly, the benefit of more green space for achieving a healthier duration of sleep was not explained by controls for psychological distress, physical activity, and socioeconomic variables

Strengths and Limitations

- This study benefits from a large sample size focusing on adults in middle-to-older age, who simultaneously shoulder the vast burden of chronic disease and are the biggest users of health services
- This study is strengthened by use of validated measures of sleep duration, psychological distress, physical activity, and an objective measure of green space exposure
- Cross-sectional data prohibits causal inference, though follow up of the participants across time will allow the opportunity for replication of this study with a longitudinal design

Introduction

Positive psychological and physiological outcomes from exposure to parks and other forms of natural environment in experimental studies [1-3] have fuelled support for the integration of these 'green spaces' within planning policy.[4 5] Health benefits are thought to accrue via psycho-neuro-endocrine pathways, wherein the experience of nature triggers restoration.[6-8] These benefits are likely to be in tandem with physical activity, more of which is not only correlated with better mental health,[9] but also increasingly likely among people who live in greener neighborhoods.[10-12]

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This hypothesis was investigated in a large sample of Australian adults in middle-to-older age, who simultaneously shoulder the vast burden of chronic disease and are the biggest users of healthcare in Australia.

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health insurance) and surveyed between 2006 and 2009. The survey response rate was 18%, though previous work has shown that results from the 45 and Up Study are comparable to those derived from a representative population survey.[27] Geocoding of participants in the 45 and Up Study was available at the Census Collection Districts (CCD) scale. CCDs contain 225 people on average and were the smallest geography at which 2006 Census data were disseminated.[28] The University of New South Wales Human Research Ethics Committee approved The 45 and Up Study.

Outcome measure

Sleep duration was derived from responses to the following question: *"About how many hours in each 24 hour day do you usually spend sleeping (including at night and naps)?"* and has been used in previous analyses of the same data.[14 15 25 29] Responses to this question were missing for 7,755 people and these were omitted from the analyses. To account for the curvilinear association between sleep duration and health,[13] responses were classified into a multinomial variable as follows: 8 hours (normal); between 9 and 10 hours (mid-long sleep); over 10 hours (long sleep); between 6 and 7 hours (mid-short sleep); less than 6 hours (short sleep). This classification allows for the healthiest duration (8 hours) to be used as a reference group for all other categories.

Green space

Meshblocks classified as 'parkland' in the Australian Bureau of Statistics (ABS) land-use classification for 2006 were used to construct the measure of green space. 'Farmland' meshblocks were not used as they do not strictly represent spaces available for recreation. The measure of green space was based upon the percentage available within a 1 kilometer (km) buffer around the population-weighted centroid of each CCD. A 1km buffer was selected so as to represent land-use within a reasonable walking distance from place of residence, **and has been used in previous studies**

of green space and health.[11 12 30 31] The percentage green space measure was classified into fifths to explore for potential non-linearities (0-20%, 20-40%, 40-60%, 60-80%, 80%+).

Other individual and neighborhood measures

The Kessler Psychological Distress Scale (K10) was used to assess mental health status.[32 33] The K10 measures symptoms of psychological distress experienced over the past four weeks, including feeling tired for no reason, nervous, hopeless, restless, depressed, sad and worthless. Participants had five choices for each of the ten questions (none of the time =1, a little of the time =2, some of the time =3, most of the time =4, all of the time=5). The K10 is constructed by summing responses to each of the questions, with scores of 22 and over identified those with a high risk of psychological distress.[34] The K10 has been used in this way in previous published analyses of the 45 and Up Study.[35]

The measure of physical activity was an aggregate of the number of 10 minute sessions spent either walking or in moderate to vigorous physical activity (MVPA), assessed using the Active Australia Survey.[36] The question was "How many times did you do each of these activities last week?" Participants could indicate walking, moderate (e.g. gentle swimming) and vigorous (e.g. jogging) forms activity separately.

A range of other individual characteristics were also taken account of, including age, gender, ethnicity, country of birth, body mass index (BMI), annual income, highest educational qualifications, economic status (employed, unemployed, retired, inactive due to poor health), couple status, number of alcoholic drinks consumed in the last week, smoking status, language other than English spoken at home, and the Duke Social Support Index.[37]

Two other characteristics at the neighborhood-level were considered. The Socio-Economic Index for Areas (SEIFA) 'Index of Relative Socio-Economic Advantage/Disadvantage' was used to measure local socioeconomic circumstances. Differences between urban and rural areas were controlled using

the 'Accessibility / Remoteness Index of Australia' (ARIA). Like the measure of green space, both of these neighborhood indicators were created using data from 2006 to fit with the baseline questionnaire.

Statistical analysis

Cross-tabulations were used to compare the patterning of each sleep duration category according to proximity to green space and all other explanatory variables. A multinomial logit regression was used assess the risk of short sleep versus an 8-hour sleep duration (reference), accounting for longer sleeps as separate categories simultaneously within the same model. Parameters were exponentiated to relative risk ratios (RRR). RRRs over 1 indicated positive association, whereas RRRs below 1 denoted negative association. Bivariate models containing the measure of green space (fitted as a categorical variable) were initially adjusted for interactions between age and gender. The robustness of any associations found were then tested with controls for psychological distress and physical activity. Socioeconomic and other explanatory variables were then added sequentially, with any change in the potential association between green space exposure and sleep duration documented. To account for the nested data structure, the Huber-White method was utilized in all models to adjust standard errors.[38 39] The log-likelihood ratio test ($p<0.05$) was used to identify statistically significant associations. Analyses were conducted in STATA 12 (StataCorp, College Station, TX, USA).

RESULTS

In Table 1 the prevalence of sleep for 8 hour duration (adjusted for age and gender) was demonstrably higher in neighborhoods with a higher percentage of green space. This was also for sleep durations between 9 and 10 hours, but not for those of 10 hours or more. Meanwhile, the prevalence of sleep durations less than 8 hours was higher in neighborhoods with less green space. The percentage point difference reported between neighborhoods with 80%+ and less than 20% green space proximity was

3.6 for a mid-short sleep duration between 6 and 7 hours (p<0.001). A smaller, though statistically significant gap was also reported for short sleeps less than 6 hours (0.9 percentage points, p<0.001). The risk of short sleep duration (6 hours or less per day) was 4 times higher among participants at high risk of psychological distress (95%CI 3.8, 4.3), 1.5 times higher among obese people versus those normal BMI (95%CI 1.46, 1.63), 1.8 times higher among people earning less than $20,000 a year (95%CI 1.7, 1.9), 1.6 times higher for residents of the most deprived quintile of neighborhoods (95%CI 1.5, 1.7) and 1.1 times higher for those in remote and rural versus urban areas (95%CI 1.0, 1.2).

Preliminary multinomial logit regression took a bivariate format with green space as the sole predictor of sleep duration. The 259,319 participants were nested within 11,719 CCDs. Compared to participants reporting 8 hour sleep as the base category, the risk of shorter sleep durations was lower for those with access to more green space. For example, the Relative Risk Ratios (RRRs) for participants with 80%+ versus less than 20% green space was 0.86 (95%CI 0.81, 0.92) for durations between 6 and 7 hours, and 0.68 (95%CI 0.57, 0.80) for less than 6 hours sleep. In contrast, there was no association between neighborhood green space and the risk of longer sleep durations between 9 and 10 hours (RRR 1.06, 95%CI 0.99, 1.14), or over 10 hours (RRR 0.85, 95%CI 0.70, 1.03).

These results appeared to corroborate our hypothesis. However, this was founded on the basis that greener neighborhoods stimulate mental health and more active lifestyles, which would then promote a healthier duration of sleep. Ergo, we expected that the association between green space and sleep duration would be explained by controls for mental health and physical activity. Adding the K10 variable showed participants at a high risk of psychological distress were more likely to report sleeps of less and also more than 8 hours in duration (p<0.001). Conversely, adding physical activity to the model did not result in a significant association with sleep duration. Unexpectedly, and counter to our hypothesis, adjusting for these variables had negligible impact on the association between green space and sleep duration.

The final step was to interrogate the consistency of the green space parameters against other factors shown to be associated with short and long sleep duration. These variables were added sequentially to the previous model, with Figure 1 illustrating the results of the final multinomial logit regression. Many characteristics of individuals were associated with sleep duration in line with previous work, such as unemployment and sleeps of less than 6 hours (RRR 1.20, 95%CI 1.02, 1.32) and more than 10 hours (RRR 3.17, 95%CI 2.66, 3.78). Participants in more affluent and geographically remote neighborhoods were also at a lower risk of short and long sleep durations (p<0.001). Controlling for all of these variables did attenuate the negative association between green space and short sleep duration, but not fully. For participants with access to 80%+ green space within their neighborhood compared to those with less than 20%, the RRR of sleeping between 6 and 7 hours was 0.92 (95%CI 0.87, 0.98) and 0.81 (95%CI: 0.69, 0.96) for sleeps of less than 6 hours in duration. There remained no association between green space exposure and sleeps of more than 8 hours.

DISCUSSION

As countries invest in large scale green space planning policies,[4 5] it would be prudent to ask whether parks and other forms of natural environment have any other health benefits aside from those which are already widely reported (namely, better mental health and increased physical activity). This study has demonstrated that people who live in greener environs are more likely to achieve a healthier duration of sleep. The protective effect of green space was isolated to guarding against the risk of short sleep (less than 8 hours), with no association found for longer sleeps. These results were consistent after controlling for factors already known to be associated with short and long sleep and, surprisingly, were not explained by indicators of mental health and physical activity. The significance of these findings are put in context when one considers that sleep durations of less than 6 hours are consistently associated with many of the major chronic health conditions[15-19] that threaten the sustainability of health systems.[40 41] As such, these results suggest that large-scale investments in green space policy could have a wider public health benefit than has been previously acknowledged.

Restoration from access to nature can occur directly [1], although exposure to green space is undoubtedly entwined, to a potentially large extent, with active lifestyles for which parks and other public open spaces are attractive environments for participation [42]. This makes the finding that green space was associated with a healthier duration of sleep, irrespective of psychological distress or participation in physical activity, more intriguing. One possible explanation is that the physical activity variable measures participation, but not with any specific reference to the place in which it occurs. Participants scoring higher on the physical activity variable therefore do not necessarily perform those activities in the green spaces where they live and this interaction between behavior and environment may be important to control.[43] Another plausible mechanism is the dispersal of traffic density [44] and noise pollution in areas with more green space, which could otherwise have a detrimental influence on sleep duration.[45 46] No measure of traffic density or noise pollution was available for this study however. Thus, while more green space appears to be protective against a short duration of sleep, it is not yet clear whether this is demonstrably because of a direct effect on restoration that is not picked up by the K10, or if it operates via other structural processes operating at the neighborhood level. Further research on the spatial patterning of sleep duration that accounts for other structural variables, such as noise pollution, is warranted to isolate the potentially causal mechanism(s) at play.

This study benefited from a large sample size and an objective measure of green space. However, the focus on a population of 45 years and older limits the generalisability to younger people, for whom further studies are advised. The survey response rate was 18%, though previous work has shown that results from the 45 and Up Study are comparable to those from a representative survey [27]. While the cross-sectional design limits prospects for causal inference, such inferences might not be achieved with longitudinal data either, as contemporaneous exposure to green space, rather than one that is temporally lagged may be what counts most for determining sleep duration. Longitudinal studies would nevertheless be useful for testing hypotheses related to temporal effects. It is plausible that sleep duration varies across the week and during the day (e.g. naps), particularly between weekdays and weekends, but the measure of sleep available in the 45 and Up Study was generalist and could not

facilitate these more detailed enquiries. Similarly, the Active Australia Survey is a measure of overall physical activity, but did not afford a distinction between leisure and other types (e.g. active travel). **Finally, while previous work has shown that different measures of green space yield similar associations with health outcomes,[47] we recognize that not all green spaces are the same and future work should explore whether variation in subjective quality[48] or type[49] (e.g. parks versus conservation areas) results in systematic differences in health outcomes, including sleep duration.**

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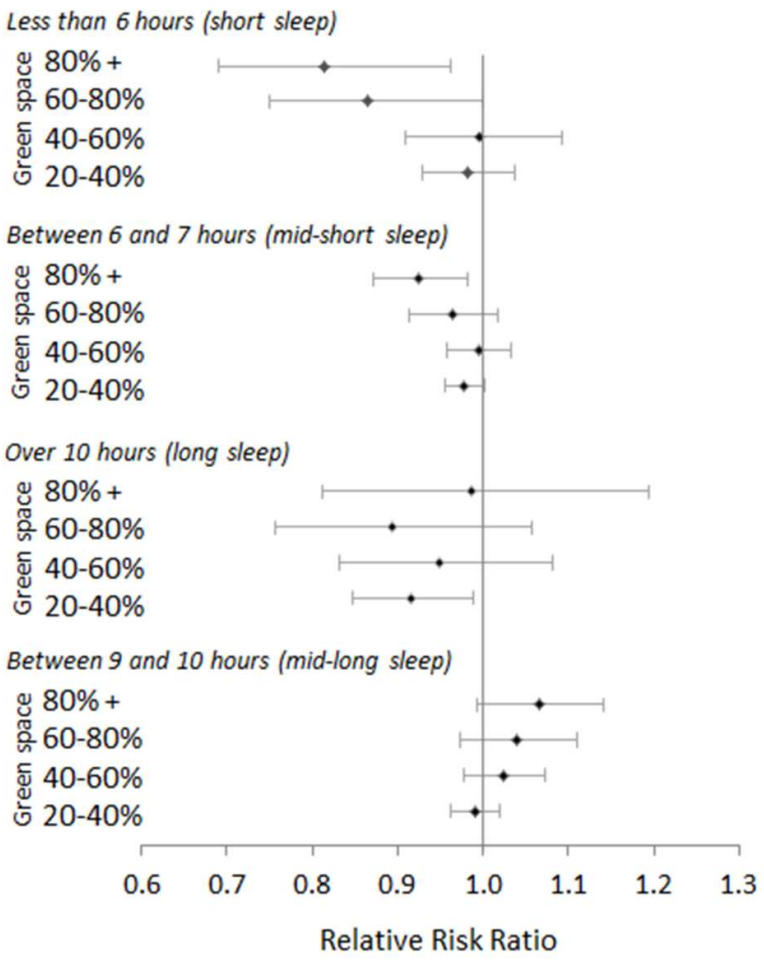
Table 1: Age-gender adjusted patterning of sleep duration by proximity to green space

	8 hours (normal)	Between 9 and 10 hours (mid-long sleep)	Over 10 hours (long sleep)	Between 6 and 7 hours (mid-short sleep)	Less than 6 hours (short sleep)
N (259,319)	104,432	47,424	4,938	92,860	9,665
Green space % (n)	% (95% Confidence Interval)				
0-20% (177,106)	40.0 (39.8, 40.3)	17.5 (17.3, 17.7)	1.6 (1.5, 1.6)	35.6 (35.3, 35.8)	3.7 (3.6, 3.8)
20-40% (49,316)	40.4 (39.9, 40.8)	16.9 (16.6, 17.3)**	1.4 (1.3, 1.5)***	36.2 (35.7, 36.7)*	3.6 (3.4, 3.8)
40-60% (18,045)	40.5 (39.7, 41.3)	17.9 (17.3, 18.6)	1.4 (1.2, 1.6)*	35.3 (34.4, 36.1)	3.3 (3.1, 3.6)**
60-80% (8,253)	41.2 (40.0, 42.3)*	18.6 (17.6, 19.6)**	1.3 (1.1, 1.5)	34.4 (33.2, 35.7)*	2.9 (2.5, 3.3)***
80% + (6,599)	41.9 (40.7, 43.2)**	20.1 (19.1, 21.2)***	1.6 (1.3, 1.9)	32.0 (30.8, 33.2)***	2.8 (2.3, 3.2)***

*** p < 0.001; ** p < 0.01; * p < 0.05 (from 0-20% green space as the reference group)

Figure 1: Association between proximity to green space and duration of sleep (fully adjusted)



*reference group = less than 20% green space

** multinomial logit regression with robust standard errors and base category comprising participants reporting 8 hours sleep duration. Models were adjusted for: age; gender; Kessler scale of psychological distress; physical activity (measured by the Active Australia survey); weight status; couple status; ethnicity; country of birth; annual household income; highest qualifications; economic status; language spoken at home; number of alcoholic drinks consumed per week; smoking status; social support; the Socio-Economic Index for Areas (SEIFA) 'Index of Relative Socio-Economic Advantage/Disadvantage'; and the 'Accessibility/Remoteness Index of Australia' (ARIA).

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Does access to neighborhood green space promote a healthy duration of sleep? Novel findings from 259,319 Australians

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ABSTRACT

Objectives: Experiments demonstrate that exposure to parks and other 'green spaces' promote favorable psychological and physiological outcomes. As a consequence, people who reside in greener neighborhoods may also have a lower risk of short sleep duration (<6 hours). This is potentially important as short sleep duration is a correlate of obesity, chronic disease, and mortality, but so far this hypothesis has not been previously investigated.

Design: Cross-sectional data analysis

Setting: New South Wales, Australia

Participants: This study investigated whether neighborhood green space was associated with a healthier duration of sleep (to the nearest hour) among 259,319 Australians who completed the 45 and Up Study baseline questionnaire between 2006 and 2009 inclusive.

Primary and secondary outcome measures: Multinomial logit regression was used to investigate the influence of an objective measure of green space on categories of sleep duration: 8 hours (normal); between 9 and 10 hours (mid-long sleep); over 10 hours (long sleep); between 6 and 7 hours (mid-short sleep); less than 6 hours (short sleep). Models were adjusted for psychological distress, physical activity, and a range of demographic and socioeconomic characteristics.

Results: People living in greener neighborhoods reported a lower risk of short sleep. For example, compared to participants living in areas with 20% green space land-use, the relative risk ratios for participants with 80%+ green space was 0.86 (95% confidence interval (95%CI) 0.81, 0.92) for durations between 6 and 7 hours, and 0.68 (95%CI 0.57, 0.80) for less than 6-hours sleep. Unexpectedly, the benefit of more green space for achieving 8 hours of sleep was not explained by controls for psychological distress, physical activity, or other socioeconomic factors.

Conclusion: Green space planning policies may have wider public health benefits than previously recognized. Further research on the role of green space in promoting healthier sleep durations and patterns is warranted.

Article Focus

- Previous work suggests that more green space within the neighborhood environment can promote better mental health and more active lifestyles
- Better mental health and more active lifestyles are correlates of a healthy duration of sleep (usually around 8 hours a night)
- Greener neighborhoods, therefore, may guard against short sleep duration (usually less than 6 hours per night), which is correlated with obesity, chronic disease, and mortality

Key Messages

- In a large study of Australian adults, we found those in greener neighborhoods were at a lower risk of short sleep (< 6 hours a night)
- More green space was not associated with longer sleep durations (which are also correlated with poor health outcomes)
- Unexpectedly, the benefit of more green space for achieving a healthier duration of sleep was not explained by controls for psychological distress, physical activity, and socioeconomic variables

Strengths and Limitations

- This study benefits from a large sample size focusing on adults in middle-to-older age, who simultaneously shoulder the vast burden of chronic disease and are the biggest users of health services
- This study is strengthened by use of validated measures of sleep duration, psychological distress, physical activity, and an objective measure of green space exposure
- Cross-sectional data prohibits causal inference, though follow up of the participants across time will allow the opportunity for replication of this study with a longitudinal design

Introduction

Positive psychological and physiological outcomes from exposure to parks and other forms of natural environment in experimental studies [1-3] have fuelled support for the integration of these 'green spaces' within planning policy.[4 5] Health benefits are thought to accrue via psycho-neuro-endocrine pathways, wherein the experience of nature triggers restoration.[6-8] These benefits are likely to be in tandem with physical activity, more of which is not only correlated with better mental health,[9] but also increasingly likely among people who live in greener neighborhoods.[10-12]

While the epidemiological literature is increasingly replete with studies documenting association between green spaces, mental health and physical activity, less attention has been paid to other important health behaviors and outcomes. One such outcome is sleep duration. Many studies have reported a parabolic association[13] between the number of hours a person sleeps and their subsequent risk of poor self-rated health [14], obesity [15 16], cardiovascular disease [17], diabetes [18 19] and death.[20-22] Favorable mental health and active lifestyles are thought to be drivers of a healthier duration of sleep (usually around 8 hours per night).[23-25] Since these drivers are widely reported to be positive outcomes of living in greener neighborhoods, we hypothesized that people with access to more green space would therefore be more likely to achieve a healthier duration of sleep.

This hypothesis was investigated in a large sample of Australian adults in middle-to-older age, who simultaneously shoulder the vast burden of chronic disease and are the biggest users of healthcare in Australia.

METHOD

Data

A sample of 259,319 participants with valid data on sleep duration were selected from 267,151 in the 45 and Up Study.[26] The questionnaire is available online from www.45andup.org.au. Participants were randomly selected from the Medicare Australia database (the national provider of universal

health insurance) and surveyed between 2006 and 2009. The survey response rate was 18%, though previous work has shown that results from the 45 and Up Study are comparable to those derived from a representative population survey.[27] Geocoding of participants in the 45 and Up Study was available at the Census Collection Districts (CCD) scale. CCDs contain 225 people on average and were the smallest geography at which 2006 Census data were disseminated.[28] The University of New South Wales Human Research Ethics Committee approved The 45 and Up Study.

Outcome measure

Sleep duration was derived from responses to the following question: *"About how many hours in each 24 hour day do you usually spend sleeping (including at night and naps)?"* and has been used in previous analyses of the same data.[14 15 25 29] Responses to this question were missing for 7,755 people and these were omitted from the analyses. To account for the curvilinear association between sleep duration and health,[13] responses were classified into a multinomial variable as follows: 8 hours (normal); between 9 and 10 hours (mid-long sleep); over 10 hours (long sleep); between 6 and 7 hours (mid-short sleep); less than 6 hours (short sleep). This classification allows for the healthiest duration (8 hours) to be used as a reference group for all other categories.

Green space

Meshblocks classified as 'parkland' in the Australian Bureau of Statistics (ABS) land-use classification for 2006 were used to construct the measure of green space. 'Farmland' meshblocks were not used as they do not strictly represent spaces available for recreation. The measure of green space was based upon the percentage available within a 1 kilometer (km) buffer around the population-weighted centroid of each CCD. A 1km buffer was selected so as to represent land-use within a reasonable walking distance from place of residence, and has been used in previous studies of

green space and health.[11 12 30 31] The percentage green space measure was classified into fifths to explore for potential non-linearities (0-20%, 20-40%, 40-60%, 60-80%, 80%+).

Other individual and neighborhood measures

The Kessler Psychological Distress Scale (K10) was used to assess mental health status.[32 33] The K10 measures symptoms of psychological distress experienced over the past four weeks, including feeling tired for no reason, nervous, hopeless, restless, depressed, sad and worthless. Participants had five choices for each of the ten questions (none of the time =1, a little of the time =2, some of the time =3, most of the time =4, all of the time=5). The K10 is constructed by summing responses to each of the questions, with scores of 22 and over identified those with a high risk of psychological distress.[34] The K10 has been used in this way in previous published analyses of the 45 and Up Study.[35]

The measure of physical activity was an aggregate of the number of 10 minute sessions spent either walking or in moderate to vigorous physical activity (MVPA), assessed using the Active Australia Survey.[36] The question was "How many times did you do each of these activities last week?" Participants could indicate walking, moderate (e.g. gentle swimming) and vigorous (e.g. jogging) forms activity separately.

A range of other individual characteristics were also taken account of, including age, gender, ethnicity, country of birth, body mass index (BMI), annual income, highest educational qualifications, economic status (employed, unemployed, retired, inactive due to poor health), couple status, number of alcoholic drinks consumed in the last week, smoking status, language other than English spoken at home, and the Duke Social Support Index.[37]

Two other characteristics at the neighborhood-level were considered. The Socio-Economic Index for Areas (SEIFA) 'Index of Relative Socio-Economic Advantage/Disadvantage' was used to measure local socioeconomic circumstances. Differences between urban and rural areas were controlled using

the 'Accessibility / Remoteness Index of Australia' (ARIA). Like the measure of green space, both of these neighborhood indicators were created using data from 2006 to fit with the baseline questionnaire.

Statistical analysis

Cross-tabulations were used to compare the patterning of each sleep duration category according to proximity to green space and all other explanatory variables. A multinomial logit regression was used assess the risk of short sleep versus an 8-hour sleep duration (reference), accounting for longer sleeps as separate categories simultaneously within the same model. Parameters were exponentiated to relative risk ratios (RRR). RRRs over 1 indicated positive association, whereas RRRs below 1 denoted negative association. Bivariate models containing the measure of green space (fitted as a categorical variable) were initially adjusted for interactions between age and gender. The robustness of any associations found were then tested with controls for psychological distress and physical activity. Socioeconomic and other explanatory variables were then added sequentially, with any change in the potential association between green space exposure and sleep duration documented. To account for the nested data structure, the Huber-White method was utilized in all models to adjust standard errors.[38 39] The log-likelihood ratio test ($p<0.05$) was used to identify statistically significant associations. Analyses were conducted in STATA 12 (StataCorp, College Station, TX, USA).

RESULTS

In Table 1 the prevalence of sleep for 8 hour duration (adjusted for age and gender) was demonstrably higher in neighborhoods with a higher percentage of green space. This was also for sleep durations between 9 and 10 hours, but not for those of 10 hours or more. Meanwhile, the prevalence of sleep durations less than 8 hours was higher in neighborhoods with less green space. The percentage point difference reported between neighborhoods with 80%+ and less than 20% green space proximity was

3.6 for a mid-short sleep duration between 6 and 7 hours (p<0.001). A smaller, though statistically significant gap was also reported for short sleeps less than 6 hours (0.9 percentage points, p<0.001). The risk of short sleep duration (6 hours or less per day) was 4 times higher among participants at high risk of psychological distress (95%CI 3.8, 4.3), 1.5 times higher among obese people versus those normal BMI (95%CI 1.46, 1.63), 1.8 times higher among people earning less than $20,000 a year (95%CI 1.7, 1.9), 1.6 times higher for residents of the most deprived quintile of neighborhoods (95%CI 1.5, 1.7) and 1.1 times higher for those in remote and rural versus urban areas (95%CI 1.0, 1.2).

Preliminary multinomial logit regression took a bivariate format with green space as the sole predictor of sleep duration. The 259,319 participants were nested within 11,719 CCDs. Compared to participants reporting 8 hour sleep as the base category, the risk of shorter sleep durations was lower for those with access to more green space. For example, the Relative Risk Ratios (RRRs) for participants with 80%+ versus less than 20% green space was 0.86 (95%CI 0.81, 0.92) for durations between 6 and 7 hours, and 0.68 (95%CI 0.57, 0.80) for less than 6 hours sleep. In contrast, there was no association between neighborhood green space and the risk of longer sleep durations between 9 and 10 hours (RRR 1.06, 95%CI 0.99, 1.14), or over 10 hours (RRR 0.85, 95%CI 0.70, 1.03).

These results appeared to corroborate our hypothesis. However, this was founded on the basis that greener neighborhoods stimulate mental health and more active lifestyles, which would then promote a healthier duration of sleep. Ergo, we expected that the association between green space and sleep duration would be explained by controls for mental health and physical activity. Adding the K10 variable showed participants at a high risk of psychological distress were more likely to report sleeps of less and also more than 8 hours in duration (p<0.001). Conversely, adding physical activity to the model did not result in a significant association with sleep duration. Unexpectedly, and counter to our hypothesis, adjusting for these variables had negligible impact on the association between green space and sleep duration.

The final step was to interrogate the consistency of the green space parameters against other factors shown to be associated with short and long sleep duration. These variables were added sequentially to the previous model, with Figure 1 illustrating the results of the final multinomial logit regression. Many characteristics of individuals were associated with sleep duration in line with previous work, such as unemployment and sleeps of less than 6 hours (RRR 1.20, 95%CI 1.02, 1.32) and more than 10 hours (RRR 3.17, 95%CI 2.66, 3.78). Participants in more affluent and geographically remote neighborhoods were also at a lower risk of short and long sleep durations (p<0.001). Controlling for all of these variables did attenuate the negative association between green space and short sleep duration, but not fully. For participants with access to 80%+ green space within their neighborhood compared to those with less than 20%, the RRR of sleeping between 6 and 7 hours was 0.92 (95%CI 0.87, 0.98) and 0.81 (95%CI: 0.69, 0.96) for sleeps of less than 6 hours in duration. There remained no association between green space exposure and sleeps of more than 8 hours.

DISCUSSION

As countries invest in large scale green space planning policies,[4 5] it would be prudent to ask whether parks and other forms of natural environment have any other health benefits aside from those which are already widely reported (namely, better mental health and increased physical activity). This study has demonstrated that people who live in greener environs are more likely to achieve a healthier duration of sleep. The protective effect of green space was isolated to guarding against the risk of short sleep (less than 8 hours), with no association found for longer sleeps. These results were consistent after controlling for factors already known to be associated with short and long sleep and, surprisingly, were not explained by indicators of mental health and physical activity. The significance of these findings are put in context when one considers that sleep durations of less than 6 hours are consistently associated with many of the major chronic health conditions[15-19] that threaten the sustainability of health systems.[40 41] As such, these results suggest that large-scale investments in green space policy could have a wider public health benefit than has been previously acknowledged.

Restoration from access to nature can occur directly [1], although exposure to green space is undoubtedly entwined, to a potentially large extent, with active lifestyles for which parks and other public open spaces are attractive environments for participation [42]. This makes the finding that green space was associated with a healthier duration of sleep, irrespective of psychological distress or participation in physical activity, more intriguing. One possible explanation is that the physical activity variable measures participation, but not with any specific reference to the place in which it occurs. Participants scoring higher on the physical activity variable therefore do not necessarily perform those activities in the green spaces where they live and this interaction between behavior and environment may be important to control.[43] Another plausible mechanism is the dispersal of traffic density [44] and noise pollution in areas with more green space, which could otherwise have a detrimental influence on sleep duration.[45 46] No measure of traffic density or noise pollution was available for this study however. Thus, while more green space appears to be protective against a short duration of sleep, it is not yet clear whether this is demonstrably because of a direct effect on restoration that is not picked up by the K10, or if it operates via other structural processes operating at the neighborhood level. Further research on the spatial patterning of sleep duration that accounts for other structural variables, such as noise pollution, is warranted to isolate the potentially causal mechanism(s) at play.

This study benefited from a large sample size and an objective measure of green space. However, the focus on a population of 45 years and older limits the generalisability to younger people, for whom further studies are advised. The survey response rate was 18%, though previous work has shown that results from the 45 and Up Study are comparable to those from a representative survey [27]. While the cross-sectional design limits prospects for causal inference, the ability to detect these types of effects might not necessarily be enhanced with longitudinal data, as contemporaneous exposure to green space, rather than one that is temporally lagged may be what counts most for determining sleep duration. Longitudinal studies would nevertheless be useful for testing hypotheses related to temporal effects and also for exploring potential confounding produced by the possibility of individuals with a propensity for healthier durations of sleep selecting into neighborhoods containing more green space.

Follow-up of the 45 and Up Study will afford these opportunities, in addition to tracking the longer-term benefits of green space for health more generally.

It is plausible that sleep duration varies across the week and during the day (e.g. naps), particularly between weekdays and weekends, but the measure of sleep available in the 45 and Up Study was generalist and could not facilitate these more detailed enquiries. Similarly, the Active Australia Survey is a measure of overall physical activity, but did not afford a distinction between leisure and other types (e.g. active travel). Finally, while previous work has shown that different measures of green space yield similar associations with health outcomes,[47] we recognize that not all green spaces are the same and future work should explore whether variation in subjective quality[48] or type[49] (e.g. parks versus conservation areas) results in systematic differences in health outcomes, including sleep duration.

In conclusion, this study has found that more green space within the neighborhood of residence is associated with a healthier duration of sleep among a large sample of Australians aged 45 and over. This association appeared to be robust to controls for mental health, physical activity, and other possible individual-level confounders, though unmeasured phenomena operating at the neighborhood-level, such as traffic density, ought to be explored as data becomes available. As it stands, people living in greener areas tend to be at a lower risk of short sleep duration and this could have important subsequent impacts on health, including obesity and cardiovascular disease. It is also plausible that healthier sleep durations promoted by exposure to green space may aid mental health and participation in physical activity. As such, future studies employing longitudinal techniques may consider investigating sleep duration as a possible mediator of associations between green space and health outcomes.

Ethics: The University of New South Wales Human Research Ethics Committee approved The 45 and Up Study. Local ethical approval for this study was awarded by the University of Western Sydney.

Funding: No funding was sought for this study.

Data sharing: Data from the 45 and Up Study is only accessible via a data license issued through blinded peer-review. It is not available for sharing with parties who do not possess an approved Agreement with the Data Custodian.

Competing Interests: None

Contributorship:

Conceived and designed the experiments: TAB XF GK

Performed the experiments: TAB XF.

Analyzed the data: TAB XF.

Wrote the paper: TAB XF GK

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Table 1: Age-gender adjusted patterning of sleep duration by proximity to green space

	8 hours (normal)	Between 9 and 10 hours (mid-long sleep)	Over 10 hours (long sleep)	Between 6 and 7 hours (mid-short sleep)	Less than 6 hours (short sleep)
N (259,319)	104,432	47,424	4,938	92,860	9,665
Green space % (n)	% (95% Confidence Interval)				
0-20% (177,106)	40.0 (39.8, 40.3)	17.5 (17.3, 17.7)	1.6 (1.5, 1.6)	35.6 (35.3, 35.8)	3.7 (3.6, 3.8)
20-40% (49,316)	40.4 (39.9, 40.8)	16.9 (16.6, 17.3)**	1.4 (1.3, 1.5)***	36.2 (35.7, 36.7)*	3.6 (3.4, 3.8)
40-60% (18,045)	40.5 (39.7, 41.3)	17.9 (17.3, 18.6)	1.4 (1.2, 1.6)*	35.3 (34.4, 36.1)	3.3 (3.1, 3.6)**
60-80% (8,253)	41.2 (40.0, 42.3)*	18.6 (17.6, 19.6)**	1.3 (1.1, 1.5)	34.4 (33.2, 35.7)*	2.9 (2.5, 3.3)***
80% + (6,599)	41.9 (40.7, 43.2)**	20.1 (19.1, 21.2)***	1.6 (1.3, 1.9)	32.0 (30.8, 33.2)***	2.8 (2.3, 3.2)***

*** p < 0.001; ** p < 0.01; * p < 0.05 (from 0-20% green space as the reference group)

Figure 1: Association between proximity to green space and duration of sleep (fully adjusted)

*reference group = less than 20% green space

** multinomial logit regression with robust standard errors and base category comprising participants reporting 8 hours sleep duration. Models were adjusted for: age; gender; Kessler scale of psychological distress; physical activity (measured by the Active Australia survey); weight status; couple status; ethnicity; country of birth; annual household income; highest qualifications; economic status; language spoken at home; number of alcoholic drinks consumed per week; smoking status; social support; the Socio-Economic Index for Areas (SEIFA) 'Index of Relative Socio-Economic Advantage/Disadvantage'; and the 'Accessibility/Remoteness Index of Australia' (ARIA).

Does access to neighborhood green space promote a healthy duration of sleep? Novel findings from 259,319 Australians

ABSTRACT

Objectives: Experiments demonstrate that exposure to parks and other 'green spaces' promote favorable psychological and physiological outcomes. As a consequence, people who reside in greener neighborhoods may also have a lower risk of short sleep duration (<6 hours). This is potentially important as short sleep duration is a correlate of obesity, chronic disease, and mortality, but so far this hypothesis has not been previously investigated.

Design: Cross-sectional data analysis

Setting: New South Wales, Australia

Participants: This study investigated whether neighborhood green space was associated with a healthier duration of sleep (to the nearest hour) among 259,319 Australians who completed the 45 and Up Study baseline questionnaire between 2006 and 2009 inclusive.

Primary and secondary outcome measures: Multinomial logit regression was used to investigate the influence of an objective measure of green space on categories of sleep duration: 8 hours (normal); between 9 and 10 hours (mid-long sleep); over 10 hours (long sleep); between 6 and 7 hours (mid-short sleep); less than 6 hours (short sleep). Models were adjusted for psychological distress, physical activity, and a range of demographic and socioeconomic characteristics.

Results: People living in greener neighborhoods reported a lower risk of short sleep. For example, compared to participants living in areas with 20% green space land-use, the relative risk ratios for participants with 80%+ green space was 0.86 (95% confidence interval (95%CI) 0.81, 0.92) for durations between 6 and 7 hours, and 0.68 (95%CI 0.57, 0.80) for less than 6-hours sleep. Unexpectedly, the benefit of more green space for achieving 8 hours of sleep was not explained by controls for psychological distress, physical activity, or other socioeconomic factors.

Conclusion: Green space planning policies may have wider public health benefits than previously recognized. Further research on the role of green space in promoting healthier sleep durations and patterns is warranted.

Ethics: The University of New South Wales Human Research Ethics Committee approved The 45 and Up Study. Local ethical approval for this study was awarded by the University of Western Sydney.

Funding: No funding was sought for this study.

Data sharing: Data from the 45 and Up Study is only accessible via a data license issued through blinded peer-review. It is not available for sharing with parties who do not possess an approved Agreement with the Data Custodian.

Article Focus

- Previous work suggests that more green space within the neighborhood environment can promote better mental health and more active lifestyles
- Better mental health and more active lifestyles are correlates of a healthy duration of sleep (usually around 8 hours a night)
- Greener neighborhoods, therefore, may guard against short sleep duration (usually less than 6 hours per night), which is correlated with obesity, chronic disease, and mortality

Key Messages

- In a large study of Australian adults, we found those in greener neighborhoods were at a lower risk of short sleep (< 6 hours a night)
- More green space was not associated with longer sleep durations (which are also correlated with poor health outcomes)
- Unexpectedly, the benefit of more green space for achieving a healthier duration of sleep was not explained by controls for psychological distress, physical activity, and socioeconomic variables

Strengths and Limitations

- This study benefits from a large sample size focusing on adults in middle-to-older age, who simultaneously shoulder the vast burden of chronic disease and are the biggest users of health services
- This study is strengthened by use of validated measures of sleep duration, psychological distress, physical activity, and an objective measure of green space exposure
- Cross-sectional data prohibits causal inference, though follow up of the participants across time will allow the opportunity for replication of this study with a longitudinal design

Introduction

Positive psychological and physiological outcomes from exposure to parks and other forms of natural environment in experimental studies [1-3] have fuelled support for the integration of these 'green spaces' within planning policy.[4 5] Health benefits are thought to accrue via psycho-neuro-endocrine pathways, wherein the experience of nature triggers restoration.[6-8] These benefits are likely to be in tandem with physical activity, more of which is not only correlated with better mental health,[9] but also increasingly likely among people who live in greener neighborhoods.[10-12]

While the epidemiological literature is increasingly replete with studies documenting association between green spaces, mental health and physical activity, less attention has been paid to other important health behaviors and outcomes. One such outcome is sleep duration. Many studies have reported a parabolic association[13] between the number of hours a person sleeps and their subsequent risk of poor self-rated health [14], obesity [15 16], cardiovascular disease [17], diabetes [18 19] and death.[20-22] Favorable mental health and active lifestyles are thought to be drivers of a healthier duration of sleep (usually around 8 hours per night).[23-25] Since these drivers are widely reported to be positive outcomes of living in greener neighborhoods, we hypothesized that people with access to more green space would therefore be more likely to achieve a healthier duration of sleep.

This hypothesis was investigated in a large sample of Australian adults in middle-to-older age, who simultaneously shoulder the vast burden of chronic disease and are the biggest users of healthcare in Australia.

METHOD

Data

A sample of 259,319 participants with valid data on sleep duration were selected from 267,151 in the 45 and Up Study.[26] The questionnaire is available online from www.45andup.org.au. Participants were randomly selected from the Medicare Australia database (the national provider of universal

health insurance) and surveyed between 2006 and 2009. The survey response rate was 18%, though previous work has shown that results from the 45 and Up Study are comparable to those derived from a representative population survey.[27] Geocoding of participants in the 45 and Up Study was available at the Census Collection Districts (CCD) scale. CCDs contain 225 people on average and were the smallest geography at which 2006 Census data were disseminated.[28] The University of New South Wales Human Research Ethics Committee approved The 45 and Up Study.

Outcome measure

Sleep duration was derived from responses to the following question: *"About how many hours in each 24 hour day do you usually spend sleeping (including at night and naps)?"* and has been used in previous analyses of the same data.[14 15 25 29] Responses to this question were missing for 7,755 people and these were omitted from the analyses. To account for the curvilinear association between sleep duration and health,[13] responses were classified into a multinomial variable as follows: 8 hours (normal); between 9 and 10 hours (mid-long sleep); over 10 hours (long sleep); between 6 and 7 hours (mid-short sleep); less than 6 hours (short sleep). This classification allows for the healthiest duration (8 hours) to be used as a reference group for all other categories.

Green space

Meshblocks classified as 'parkland' in the Australian Bureau of Statistics (ABS) land-use classification for 2006 were used to construct the measure of green space. 'Farmland' meshblocks were not used as they do not strictly represent spaces available for recreation. The measure of green space was based upon the percentage available within a 1 kilometer (km) buffer around the population-weighted centroid of each CCD. A 1km buffer was selected so as to represent land-use within a reasonable walking distance from place of residence, and has been used in previous studies of

green space and health.[11 12 30 31] The percentage green space measure was classified into fifths to explore for potential non-linearities (0-20%, 20-40%, 40-60%, 60-80%, 80%+).

Other individual and neighborhood measures

The Kessler Psychological Distress Scale (K10) was used to assess mental health status.[32 33] The K10 measures symptoms of psychological distress experienced over the past four weeks, including feeling tired for no reason, nervous, hopeless, restless, depressed, sad and worthless. Participants had five choices for each of the ten questions (none of the time =1, a little of the time =2, some of the time =3, most of the time =4, all of the time=5). The K10 is constructed by summing responses to each of the questions, with scores of 22 and over identified those with a high risk of psychological distress.[34] The K10 has been used in this way in previous published analyses of the 45 and Up Study.[35]

The measure of physical activity was an aggregate of the number of 10 minute sessions spent either walking or in moderate to vigorous physical activity (MVPA), assessed using the Active Australia Survey.[36] The question was "How many times did you do each of these activities last week?" Participants could indicate walking, moderate (e.g. gentle swimming) and vigorous (e.g. jogging) forms activity separately.

A range of other individual characteristics were also taken account of, including age, gender, ethnicity, country of birth, body mass index (BMI), annual income, highest educational qualifications, economic status (employed, unemployed, retired, inactive due to poor health), couple status, number of alcoholic drinks consumed in the last week, smoking status, language other than English spoken at home, and the Duke Social Support Index.[37]

Two other characteristics at the neighborhood-level were considered. The Socio-Economic Index for Areas (SEIFA) 'Index of Relative Socio-Economic Advantage/Disadvantage' was used to measure local socioeconomic circumstances. Differences between urban and rural areas were controlled using

the 'Accessibility / Remoteness Index of Australia' (ARIA). Like the measure of green space, both of these neighborhood indicators were created using data from 2006 to fit with the baseline questionnaire.

Statistical analysis

Cross-tabulations were used to compare the patterning of each sleep duration category according to proximity to green space and all other explanatory variables. A multinomial logit regression was used assess the risk of short sleep versus an 8-hour sleep duration (reference), accounting for longer sleeps as separate categories simultaneously within the same model. Parameters were exponentiated to relative risk ratios (RRR). RRRs over 1 indicated positive association, whereas RRRs below 1 denoted negative association. Bivariate models containing the measure of green space (fitted as a categorical variable) were initially adjusted for interactions between age and gender. The robustness of any associations found were then tested with controls for psychological distress and physical activity. Socioeconomic and other explanatory variables were then added sequentially, with any change in the potential association between green space exposure and sleep duration documented. To account for the nested data structure, the Huber-White method was utilized in all models to adjust standard errors.[38 39] The log-likelihood ratio test ($p<0.05$) was used to identify statistically significant associations. Analyses were conducted in STATA 12 (StataCorp, College Station, TX, USA).

RESULTS

In Table 1 the prevalence of sleep for 8 hour duration (adjusted for age and gender) was demonstrably higher in neighborhoods with a higher percentage of green space. This was also for sleep durations between 9 and 10 hours, but not for those of 10 hours or more. Meanwhile, the prevalence of sleep durations less than 8 hours was higher in neighborhoods with less green space. The percentage point difference reported between neighborhoods with 80%+ and less than 20% green space proximity was

3.6 for a mid-short sleep duration between 6 and 7 hours (p<0.001). A smaller, though statistically significant gap was also reported for short sleeps less than 6 hours (0.9 percentage points, p<0.001). The risk of short sleep duration (6 hours or less per day) was 4 times higher among participants at high risk of psychological distress (95%CI 3.8, 4.3), 1.5 times higher among obese people versus those normal BMI (95%CI 1.46, 1.63), 1.8 times higher among people earning less than $20,000 a year (95%CI 1.7, 1.9), 1.6 times higher for residents of the most deprived quintile of neighborhoods (95%CI 1.5, 1.7) and 1.1 times higher for those in remote and rural versus urban areas (95%CI 1.0, 1.2).

Preliminary multinomial logit regression took a bivariate format with green space as the sole predictor of sleep duration. The 259,319 participants were nested within 11,719 CCDs. Compared to participants reporting 8 hour sleep as the base category, the risk of shorter sleep durations was lower for those with access to more green space. For example, the Relative Risk Ratios (RRRs) for participants with 80%+ versus less than 20% green space was 0.86 (95%CI 0.81, 0.92) for durations between 6 and 7 hours, and 0.68 (95%CI 0.57, 0.80) for less than 6 hours sleep. In contrast, there was no association between neighborhood green space and the risk of longer sleep durations between 9 and 10 hours (RRR 1.06, 95%CI 0.99, 1.14), or over 10 hours (RRR 0.85, 95%CI 0.70, 1.03).

These results appeared to corroborate our hypothesis. However, this was founded on the basis that greener neighborhoods stimulate mental health and more active lifestyles, which would then promote a healthier duration of sleep. Ergo, we expected that the association between green space and sleep duration would be explained by controls for mental health and physical activity. Adding the K10 variable showed participants at a high risk of psychological distress were more likely to report sleeps of less and also more than 8 hours in duration (p<0.001). Conversely, adding physical activity to the model did not result in a significant association with sleep duration. Unexpectedly, and counter to our hypothesis, adjusting for these variables had negligible impact on the association between green space and sleep duration.

The final step was to interrogate the consistency of the green space parameters against other factors shown to be associated with short and long sleep duration. These variables were added sequentially to the previous model, with Figure 1 illustrating the results of the final multinomial logit regression. Many characteristics of individuals were associated with sleep duration in line with previous work, such as unemployment and sleeps of less than 6 hours (RRR 1.20, 95%CI 1.02, 1.32) and more than 10 hours (RRR 3.17, 95%CI 2.66, 3.78). Participants in more affluent and geographically remote neighborhoods were also at a lower risk of short and long sleep durations (p<0.001). Controlling for all of these variables did attenuate the negative association between green space and short sleep duration, but not fully. For participants with access to 80%+ green space within their neighborhood compared to those with less than 20%, the RRR of sleeping between 6 and 7 hours was 0.92 (95%CI 0.87, 0.98) and 0.81 (95%CI: 0.69, 0.96) for sleeps of less than 6 hours in duration. There remained no association between green space exposure and sleeps of more than 8 hours.

DISCUSSION

As countries invest in large scale green space planning policies,[4 5] it would be prudent to ask whether parks and other forms of natural environment have any other health benefits aside from those which are already widely reported (namely, better mental health and increased physical activity). This study has demonstrated that people who live in greener environs are more likely to achieve a healthier duration of sleep. The protective effect of green space was isolated to guarding against the risk of short sleep (less than 8 hours), with no association found for longer sleeps. These results were consistent after controlling for factors already known to be associated with short and long sleep and, surprisingly, were not explained by indicators of mental health and physical activity. The significance of these findings are put in context when one considers that sleep durations of less than 6 hours are consistently associated with many of the major chronic health conditions[15-19] that threaten the sustainability of health systems.[40 41] As such, these results suggest that large-scale investments in green space policy could have a wider public health benefit than has been previously acknowledged.

Restoration from access to nature can occur directly [1], although exposure to green space is undoubtedly entwined, to a potentially large extent, with active lifestyles for which parks and other public open spaces are attractive environments for participation [42]. This makes the finding that green space was associated with a healthier duration of sleep, irrespective of psychological distress or participation in physical activity, more intriguing. One possible explanation is that the physical activity variable measures participation, but not with any specific reference to the place in which it occurs. Participants scoring higher on the physical activity variable therefore do not necessarily perform those activities in the green spaces where they live and this interaction between behavior and environment may be important to control.[43] Another plausible mechanism is the dispersal of traffic density [44] and noise pollution in areas with more green space, which could otherwise have a detrimental influence on sleep duration.[45 46] No measure of traffic density or noise pollution was available for this study however. Thus, while more green space appears to be protective against a short duration of sleep, it is not yet clear whether this is demonstrably because of a direct effect on restoration that is not picked up by the K10, or if it operates via other structural processes operating at the neighborhood level. Further research on the spatial patterning of sleep duration that accounts for other structural variables, such as noise pollution, is warranted to isolate the potentially causal mechanism(s) at play.

This study benefited from a large sample size and an objective measure of green space. However, the focus on a population of 45 years and older limits the generalisability to younger people, for whom further studies are advised. The survey response rate was 18%, though previous work has shown that results from the 45 and Up Study are comparable to those from a representative survey [27]. While the cross-sectional design limits prospects for causal inference, the ability to detect these types of effects might not necessarily be enhanced with longitudinal data, as contemporaneous exposure to green space, rather than one that is temporally lagged may be what counts most for determining sleep duration. **Longitudinal studies would nevertheless be useful for testing hypotheses related to temporal effects and also for exploring potential confounding produced by the possibility of individuals with a propensity for healthier durations of sleep selecting into neighborhoods**

containing more green space. Follow-up of the 45 and Up Study will afford these opportunities, in addition to tracking the longer-term benefits of green space for health more generally.

It is plausible that sleep duration varies across the week and during the day (e.g. naps), particularly between weekdays and weekends, but the measure of sleep available in the 45 and Up Study was generalist and could not facilitate these more detailed enquiries. Similarly, the Active Australia Survey is a measure of overall physical activity, but did not afford a distinction between leisure and other types (e.g. active travel). Finally, while previous work has shown that different measures of green space yield similar associations with health outcomes,[47] we recognize that not all green spaces are the same and future work should explore whether variation in subjective quality[48] or type[49] (e.g. parks versus conservation areas) results in systematic differences in health outcomes, including sleep duration.

In conclusion, this study has found that more green space within the neighborhood of residence is associated with a healthier duration of sleep among a large sample of Australians aged 45 and over. This association appeared to be robust to controls for mental health, physical activity, and other possible individual-level confounders, though unmeasured phenomena operating at the neighborhood-level, such as traffic density, ought to be explored as data becomes available. As it stands, people living in greener areas tend to be at a lower risk of short sleep duration and this could have important subsequent impacts on health, including obesity and cardiovascular disease. It is also plausible that healthier sleep durations promoted by exposure to green space may aid mental health and participation in physical activity. As such, future studies employing longitudinal techniques may consider investigating sleep duration as a possible mediator of associations between green space and health outcomes.

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Table 1: Age-gender adjusted patterning of sleep duration by proximity to green space

	8 hours (normal)	Between 9 and 10 hours (mid-long sleep)	Over 10 hours (long sleep)	Between 6 and 7 hours (mid-short sleep)	Less than 6 hours (short sleep)
N (259,319)	104,432	47,424	4,938	92,860	9,665
Green space % (n)	% (95% Confidence Interval)				
0-20% (177,106)	40.0 (39.8, 40.3)	17.5 (17.3, 17.7)	1.6 (1.5, 1.6)	35.6 (35.3, 35.8)	3.7 (3.6, 3.8)
20-40% (49,316)	40.4 (39.9, 40.8)	16.9 (16.6, 17.3)**	1.4 (1.3, 1.5)***	36.2 (35.7, 36.7)*	3.6 (3.4, 3.8)
40-60% (18,045)	40.5 (39.7, 41.3)	17.9 (17.3, 18.6)	1.4 (1.2, 1.6)*	35.3 (34.4, 36.1)	3.3 (3.1, 3.6)**
60-80% (8,253)	41.2 (40.0, 42.3)*	18.6 (17.6, 19.6)**	1.3 (1.1, 1.5)	34.4 (33.2, 35.7)*	2.9 (2.5, 3.3)***
80% + (6,599)	41.9 (40.7, 43.2)**	20.1 (19.1, 21.2)***	1.6 (1.3, 1.9)	32.0 (30.8, 33.2)***	2.8 (2.3, 3.2)***

*** p < 0.001; ** p < 0.01; * p < 0.05 (from 0-20% green space as the reference group)

Figure 1: Association between proximity to green space and duration of sleep (fully adjusted)

*reference group = less than 20% green space

** multinomial logit regression with robust standard errors and base category comprising participants reporting 8 hours sleep duration. Models were adjusted for: age; gender; Kessler scale of psychological distress; physical activity (measured by the Active Australia survey); weight status; couple status; ethnicity; country of birth; annual household income; highest qualifications; economic status; language spoken at home; number of alcoholic drinks consumed per week; smoking status; social support; the Socio-Economic Index for Areas (SEIFA) 'Index of Relative Socio-Economic Advantage/Disadvantage'; and the 'Accessibility/Remoteness Index of Australia' (ARIA).

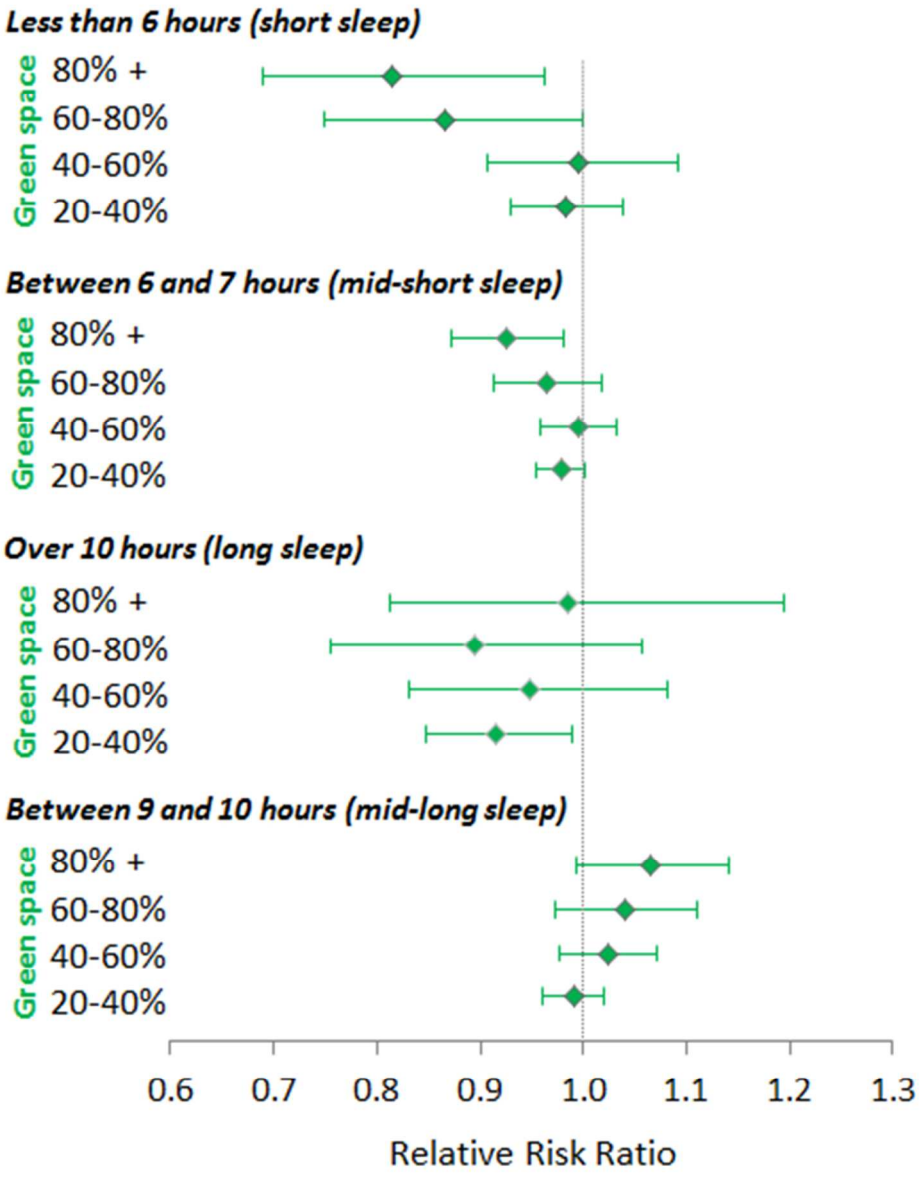

Figure 1
119x149mm (300 x 300 DPI)