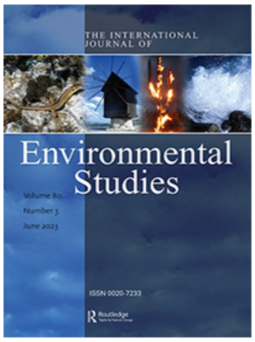

International Journal of Environmental Studies

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/genv20

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To cite this article: Katri Savolainen (2023): Nature exposure is not associated with parent-reported or objectively measured sleep quality in 6-year-old children – a study in Finland, International Journal of Environmental Studies, DOI: 10.1080/00207233.2023.2222611

To link to this article: https://doi.org/10.1080/00207233.2023.2222611

Published online: 14 Jun 2023.

INTERNATIONAL JOURNAL OF ENVIRONMENTAL STUDIES
https://doi.org/10.1080/00207233.2023.2222611

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Nature exposure is not associated with parent-reported or objectively measured sleep quality in 6-year-old children – a study in Finland

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ABSTRACT
Exposure to green environments has been associated with better sleep quality in adults. This study examined whether nature exposure is associated with parent-reported or actigraphy measured sleep quality in children. Against the hypotheses, no differences in sleep quality between the case and control groups or a moderating effect of socioeconomic status or sex were found. Green environment exposure may not serve as an environmental intervention to increase sleep quality in children.

KEYWORDS
Nature; environment; objective; actigraphy; sleep; children

Introduction

Insufficient sleep and poor sleep quality are associated with a wide range of physical and mental health problems. They have been shown to have direct or bi-directional associations with, e.g. stress levels, depression, anxiety, cognitive functioning, chronic diseases, and obesity both in adults and children [1–3]. Poor sleep not only has impacts on individual level but also has major financial costs for societies [4]. It has been estimated that in the United States alone, a financial loss of $411 billion or 2.28% of the GDP in 2015, was associated with insufficient sleep [5]. Finding effective ways to improve the quality and quantity of sleep at the population-level would, thus, have an impact on both subjective well-being and financial costs at the societal level.

There has been promising evidence indicating that exposure to green environments may hold potential for prevention of insufficient sleep. Exposure to green environments has been associated with very similar health and well-being effects that have been linked to better sleep quality. Exposure to greenery has been shown to buffer the adverse health effects of urban living, provide better mental and physical health, and to be associated with higher cognitive capacity and memory, and lower stress levels, both in adults and children [6–12]. And thus, it is not surprising that exposure to a green environment has also been associated with better sleep quality in most of the studies conducted [13]. The recent and the first systematic review on green space exposure and sleep quality found 13 studies on the subject matter [13]; out of which 11 studies concluded that green space exposure was associated with improvement in sleep quality [13]. These findings led to a

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Published online 14 Jun 2023

suggestion that building green spaces and leaving unmodified nature areas in urban environments, may serve as a potential environmental intervention to increase the sleep quality at the population level.

Nevertheless, remarkably little is known about how the green environment affects children's sleep quality and quantity. As children's overall stage in development, sleep architecture, and need for sleep are different from teenagers and adults [14,15], the results from studies in adults or youth cannot be generalised into younger children. In the systematic review by Shin et al. on green environment and sleep, 12 out of 13 studies included only adults [13] and the sole study including also children had grouped both younger and older children, aged between 6 and 17 years, in the same analyses [16]. In addition to the literature search made by Shin et al., only three recent studies researching green environment and sleep concerning children were found. Two of the studies included only older pre-teens or teenagers, aged between 10 and 15 years [17] and 12 and 17 years [18] and only one study by Reuben et al. has explored the effects on younger children of a green environment [19]. Reuben et al. showed that having parks around the home address was associated significantly more often with parent-reported inadequate amount of sleep for children aged between 0 and 5 and 6 and 12 years but not for children of 13–17 years old [19]. As the study by Reuben et al. is based on just one parent-reported question on sleep quantity [19], the current literature on green exposure, and children's sleep quality is very limited. There is an urgent need for better understanding on the effects that green exposure has on younger children's sleep.

In addition to mixing younger children and teens in the same analyses, previous studies on green exposure and sleep quality in youth have two other methodological difficulties that complicate drawing strong conclusions from the results. First, using the green space around home as a marker of a nature exposure is problematic, as children like adults have become more sedentary. Children are spending more and more time indoors, with organised hobbies and institutions. The existence of the green places does not reliably reflect the *actual time spent in greenery* [20]. It is therefore suggested that actual visits to places outdoors where greenery is abundant, rather than greenery around the home, should be used when studying the effect of a green environment on well-being [21]. All the previous studies on the green environment and youth's sleep quality have used the existence of parks and green areas near the home as indicator of green space exposure [16,18,19,22]. Second, in three out of four studies on green space and sleep in youth, the evaluation of sleep quality was based on just one [16,19] or two [17] parent-reported questions on sleep quality. Although parents have been shown to report relatively accurately sleep-schedule measures, e.g. sleep onset and sleep duration, they are *less accurate* in assessing sleep quality measures and are overestimating the time that children spent in actual sleep and underestimating the number of awakenings during the night [23]. Therefore, it is often suggested that subjective and objective measures should play a complementary role in sleep evaluation in childhood.

Study aims and hypotheses

In general, the current literature lacks studies on the effect of objectively measured exposure to green environment and sleep quality in younger children. Thus, the first aim of the present study was to fill the gap in the literature and study whether continuous and objectively measured nature exposure is associated with both subjectively and objectively measured sleep quality in 6-year-old children. The study hypothesis was that nature exposure may associate with better sleep quality.

As the recent study by Jimenez et al. reported preliminary findings showing that socio-economic status (SES) can modify the association between greenery and sleep quality in teenagers [18], the second aim of the present study was to analyse whether the moderating effect of SES can be replicated in the younger sample. Based on the previous findings [18], the hypothesis was that green space exposure may have more beneficial effects on children's sleep in the higher SES group. The moderating effect of sex (girl/boy) was also explored.

Methods

Study design and participants

In Finland, the municipalities have the responsibility of organising free preschool education of 4 h per working day (20 h/week) for all children living in the area. The curriculum of education is fixed, but municipalities have the right and freedom to organise education in different ways. Most commonly, the preschools organise their activities inside the day care centre or school, and the daily outdoor activities are carried out in a built playground area around the centre. These typical types of preschools make field trips to unspoilt natural sites only every now and then. There are also some preschool groups, called the nature-preschools, which devote a significant amount of time or all of it (up to a full 20 h/week) to preschool activities regularly in unspoilt natural sites, typically in nearby forest. Typically, children attend a preschool near their home, which can be either a nature-preschool or a typical preschool. Nature-preschools offer a desirable method to study the effects of nature exposure in preschool-age children.

The study includes 14 nature-preschool groups around Finland and 13 typical preschool groups in the same municipality areas. All the 27 preschool groups invited to the study were willing to attend. A total of 380 families were invited to the study, and of them, 150 (39.5%) participated. Data collection was performed after the children had been in the preschool on average 4.5 (range = 2.3–8.4, SD = 1.8) months. These 150 participants form the study population for the subjective sleep quality analyses. The study population is described previously in more detail [24].

From the 150 preschool-age children, $N = 50$ randomly selected children ($N = 30$ attending nature-preschools and $N = 20$ attending typical preschools) attended 48 h actigraphy measurement and form the study population for the objective sleep quality analyses. The actigraphy measurements were performed during a typical preschool week. It was ascertained from the parents that during the recording days the children in nature-preschool were taking part in typical teaching days in nature and children in typical preschools were attending preschool activities indoors and at the day care centres' playgrounds. If the children were sick at the time of the planned recording days, the days were changed. The measurement was started without delay after awakening on the first recording day and ended after awakening after the second recording night.

Ethics statement

The study is run under the ethical rules of the Ethics Committee of the University of Jyväskylä (Finland), which follows the Finnish nationwide ethical guidelines of the Finnish Advisory Board on Research Integrity (TENK). According to TENK guidelines, the study protocol did not present any risk of harm that would have caused further ethics committee evaluation (see Appendix 1). Written research permission was obtained from all the attending municipalities. All guardians of the study participants gave their written informed consent before the children attended the study.

Objective nature exposure

All the children attending the study were attending municipality-organised preschool. The objective time spent in nature during the typical preschool day was obtained from preschool managers. Nature-preschool groups spent on average 13.1 (SD = 3.55) h/week in nature and typical preschool groups on average 1.7 (SD = 0.88) h/week in nature. The children attending nature-preschool are referred to hereafter as children with objective nature exposure and children attending typical preschool as children without objective nature exposure.

Parent-reported sleep quality

A short version of Children's Sleep Habit Questionnaire (CSHQ) was used to evaluate the parent-reported sleep quality. CSHQ is a retrospective parent-reported questionnaire that has been developed for children aged 4–10 years of age for screening childhood sleep disorders over a typical week [25]. A version of CSHQ, with 31 items, was used in the present study. And thus, compared to the original questionnaire [25] the daytime sleepiness subscale is calculated with six items, instead of eight. There are several previous studies that have shown that shorter versions of CSHQ can be used to evaluate sleep quality in children [26–28]. Versions of 24 items [28], 23 items [26] and 19 items [27] have been used.

Questions in the CSHQ are rated on a 3-point Likert-type scale (rarely/0–1 times per week = 1, sometimes/2–4 times per week = 2, usually/5–7 times per week = 3), assessing the frequency of sleep disturbances [25]. CSHQ provides a total sum score (range = 31–93 in this study). A higher value indicates more sleep problems. CSHQ includes the following subscales: bedtime resistance (range = 8–24), sleep onset delay (range = 1–3), sleep duration (range = 3–9), sleep anxiety (range = 4–12), night wakings (range = 3–9), parasomnias (range = 7–21), sleep-disordered breathing (range = 3–9), and daytime sleepiness (range = 6–18 in this study) [25]. The internal reliability (Cronbach's α) of 31-item short version of CSHQ in this study was 0.70.

Objective sleep quality

Objective sleep quality was measured using accelerometer ActiGraph GT3X+ (ActiGraph, Pensacola, USA). Children wore actigraphy on the non-dominant wrist for 48 h, including two overnight periods during a typical preschool week. ActiGraph

GT3X+ worn at the wrist has been shown to be a good movement-based measurement tool for sleep quality metrics in 5- to 8-year-old children [29].

The devices were initialised using 10 s epochs and processed with the normal frequency filter. For sleep parameter calculations, 60 s epoch data was reintegrated from the original 10 s epochs. Sadeh algorithm [30] was used for assessing sleep quality parameters. Sadeh algorithm is a commonly used algorithm in children and is has been well validated also in children against polysomnography [30–32]. The following parameters were gathered from the data: sleep latency, total sleep time, wake after sleep onset, efficiency, number of awakenings (>1 min), duration of >15 min awakenings, and fragmentation index. A minimum of 22 h measurement across 24 h measurement period was the chosen wear time criteria used for the subsequent analysis. All the data fulfilled the criteria. Actigraphs were initialised, data saved, and sleep parameters calculated using Actilife (V 6.13.3) software.

Socioeconomic status (SES)

SES was operationalised from a question on the parent's self-reported highest attained education. Parent was asked to report their own and their spouses highest attained education using four categories. If both the parent's highest attained education was either basic education or vocational school, the variables were recoded into value 0 ($N = 45$, 30.2%) representing the lower SES category. If either of the parent's highest attained education was bachelor's degree or higher university degree, the variables were recoded into value 1 ($N = 104$, 69.8%) representing higher SES category.

Frequency of visiting nature in free time

Frequency that the child typically visits nature during free time was collected from the parent. The parents were asked: '"When your child is outdoors, how often he/she spends time in the forest or other unspoilt natural sites (after the day care or during a day off)?"' using six categories (rarely, less frequently than weekly, once a week, twice a week, three to four times a week, and five to seven times a week). In all the analyses, the variable was recoded into a dummy variable where value 0 ($N = 55$, 36.9%) represents spending time in nature less frequently than weekly and value 1 ($N = 94$, 63.1%) spending time in nature at least once a week.

Statistical analyses

Linear regression analysis was used to examine the associations between objective nature exposure and continuous sleep quality variables and logistic regression to analyse the categorical sleep variables. Subjective and objective sleep quality variables were used as dependent variables.

All the main effect analyses were run using both dummy coded and continuous nature exposure variables. Dummy coded `nature exposure status´ variable divided children into two categories; children who attended nature-preschool and thus experienced objective nature exposure (value 1) vs. children who were attending typical preschool and thus did not experience objective nature exposure (value 0). Average time (hours) spent in nature during preschool week was used as continuous nature exposure variable.

Sum scores for CSHQ and its subscales were calculated. Six questions in CSHQ are asked in reverse form [25] and thus were reversed before calculating the continuous sum scores. Seven out of eight CSHQ subscale sum scores (bedtime resistance, sleep onset delay, sleep duration, sleep anxiety, night wakings, parasomnias, sleep-disordered breathing) were skewed to the right and thus, were natural log (ln) transformed prior to the statistical analyses. For more detailed analyses, the CSHQ sum score and all its eight subscales were dummy coded into categorical variables. Dummy coded CSHQ variables were calculated by dividing the continuous variables into two groups split from the median, where value 0 represents fewer sleep problems and value 1 more sleep problems. The median split for CSHQ sum score was used, instead of the original cut-off score 41 reported by Owens [25] because of its low threshold level documented in the previous studies. It has been shown that the original cut-off score can generate up to 96% of children to be categorised with possible sleep disturbances [33].

Objective sleep quality variables extracted from actigraphy for the two measurement nights were averaged into a mean for the analyses. Aggregated natural sleep pattern variables have been shown to be reliable when using shorter overall measurement period [34]. One Actigraph-measured objective sleep quality variable, duration of >15 min awakenings, was skewed to the right and was natural log (ln) transformed prior to the statistical analyses. The sleep latency of one child was 117 min, where for the rest of the children, the latency was less than 47 min. The sleep latency analyses were thus run both with and without the outlier value. None of the non-significant results became significant when the participant was excluded from the analyses.

Interaction effects of `SES x nature exposure status´ and `sex x nature exposure status´ were run with CSHQ sum score and objectively measured sleep variables. The interaction terms were calculated and added into the linear regression model together with the main effects.

Both unadjusted and covariate adjusted analyses were run. All the analyses first run without covariate adjustment are referred to as Model 1 analyses. All the significant results from Model 1 analyses were re-run with the following Model 2 covariates: sex, age, SES, frequency of visiting nature in free time. All the statistical analyses were carried out using SPSS 26 for Windows.

Results

The participants ($N = 150$) were on average 6.5 (SD = 0.3) years old at the time of the measurement and 73 (48.7%) of them were girls. Objectively measured sleep latency for all the children was on average 17.9 (SD = 17.9) min and objectively measured average quantity sleep for all the children time 8 h and 27 min (SD = 27.9 min). There was no difference in SES, age, sex, or time spent in nature during free time between the children with and without objective nature exposure (Model 1 p-values >0.093 See Table 1). Children with objective nature exposure spent significantly more time in nature during preschool than children without objective nature exposure (Model 1 $p < 0.001$, see Table 1, Model 2 $p < 0.001$). Children with objective nature exposure spent on average

Table 1. Background characteristics of study population (*N* = 150) divided between children with objective nature exposure and children without objective nature exposure.

	Children with objective nature exposure (*N* = 85) N (%), Mean (SD)	Children without objective nature exposure (*N* = 65) N (%), Mean (SD)	p
Time spent in nature during preschool (h/week)	13.1 (SD = 3.5)	1.7 (SD = .9)	<.001*
Frequency of visiting nature in free time (weekly)	55 (65%)	39 (61%)	.640
Age (years)	6.5 (SD = .3)	6.5 (SD = .3)	.730
Sex (girl)	39 (46%)	34 (52%)	.439
Socioeconomic status (higher)	64 (75%)	40 (62%)	.093

N = Number of cases, SD=standard deviation, * = $p < 0.05$ in Model 1 analyses.

13.1 (SD = 3.55) h/week in nature and children without objective nature exposure on average 1.7 (SD = 0.88) h/week in nature.

None of the background characteristics, including age, sex, SES, and frequency of visiting nature in free time, were associated with SCHQ sum score (Model 1 p-values >0.149). From the background characteristics, the age of the children was associated with objectively measured duration of >15 min awakenings during the night (Model 1 $p = 0.018$, 95% CI = −1.428, −0.145; Model 2 $p = 0.009$, 95% CI = −1.607, −0.251), so that older children had less 15 min or longer awake periods during the night than younger children. None of the other background characteristics were associated with objectively measured sleep variables: sleep latency, total sleep time, wake after sleep onset, sleep efficiency, number of awakenings (>1 min), fragmentation index, or duration of >15 min awakenings (Model 1 p-values >0.055).

Nature exposure and subjective sleep quality (*N* = 150)

There were no differences in parent-reported CSHQ sum score or any of its subscales between the children with and without objective nature exposure when CSHQ was used as continuous (Model 1 p-values >0.149) or binary (Model 1 p-values >0.168) variables (see Table 2). Average time spent in nature during preschool week was not associated

Table 2. Unadjusted (Model 1) differences in parent-reported CSHQ sleep variables (*N* = 150) between children with and without objective nature exposure during preschool using continuous and binary sleep variables.

CSHQ	continuous		binary[1]	
	95% CI	p	Exp(B)	p
Sum score	−0.044, 0.062	.734	.961	.904
Subscales				
Bedtime resistance	−0.090, 0.051	.586	.910	.788
Sleep onset delay	−0.138, 0.049	.346	.589	.254
Sleep duration	−0.020, 0.124	.158	1.500	.244
Sleep anxiety	−0.091, 0.060	.685	.873	.690
Night wakings	−0.122, 0.050	.405	.630	.168
Parasomnias	−0.047, 0.070	.699	1.087	.800
Sleep-disordered breathing	−0.028. 0.104	.258	1.634	.322
Daytime sleepiness	−0.117, 0.136	.883	1.176	.631

CSHQ= Child Sleep Habit Questionnaire.
1=two groups split from median value, 95% CI = 95% confidence interval, Exp(B)= Exponentiation of the B coefficient.

with CSHQ sum score or any of its subscales using continuous (Model 1 p-values >0.369) or binary (Model 1 p-values >0.463) variables either.

Nature exposure and objective sleep quality ($N = 50$)

There were no differences in any of the objectively measured sleep quality variables between the children with and without objective nature exposure (Model 1 p-values >0.238, see Table 3). Average time spent in nature during preschool week was not associated with any of the objective sleep quality variables either (Model 1 p-values >0.218).

Moderating effects of SES and sex

Neither SES nor sex moderated the association between nature exposure status (children with objective nature exposure vs. children without objective nature exposure) and subjectively measured CSHQ sum score or any of the objectively measured sleep quality variables (Model 1 p-values >0.117, see Table 4).

Table 3. Unadjusted (Model 1) differences in Actigraph measured objective sleep quality variables between children with and without objective nature exposure ($N = 50$).

Objectively measured sleep variable	95% CI	p
Sleep latency	−9.993, 11.477	.890
Total sleep time	−8.884, 34.867	.238
Wake after sleep onset	−15.802, 14.452	.929
Efficiency	−2.747, 3.145	.892
Number of awakenings (>1 min)	−2.751, 3.851	.739
Fragmentation index	−3.720, 2.080	.572
Duration of >15 min awakenings	−0.543, 0.191	.332

95% CI = 95% confidence interval.

Table 4. Unadjusted (Model 1) interaction effects of `SES x nature exposure status´ and `sex x nature exposure status´ on parent reported CSHS sum score ($N = 150$) and objectively measured sleep quality variables ($N = 50$).

	95% CI	p
`SES x nature exposure status´ -interaction		
CSHQ sum score	−0.046, 0.187	0.232
Objectively measured Sleep latency	−38.108, 8.190	0.200
Objectively measured Total sleep time	−66.203, 33.161	0.508
Objectively measured Wake after sleep onset	−31.954, 37.204	0.879
Objectively measured Efficiency	−5.820, 7.376	0.813
Objectively measured Number of awakenings (>1 min)	−7.356, 7.689	0.965
Objectively measured Fragmentation index	−8.295, 4.784	0.591
Objectively measured Duration of >15 min awakenings	−0.949, 0.733	0.794
`sex x nature exposure status´ -interaction		
CSHQ sum score	−0.130, 0.082	0.652
Objectively measured Sleep latency	−35.744, 7.695	0.200
Objectively measured Total sleep time	−47.117, 45.688	0.975
Objectively measured Wake after sleep onset	−27.974, 35.847	0.805
Objectively measured Efficiency	−4.447, 7.789	0.585
Objectively measured Number of awakenings (>1 min)	−8.221, 5.659	0.712
Objectively measured Fragmentation index	−8.872, 3.187	0.347
Objectively measured Duration of >15 min awakenings	−0.266, 1.372	0.117

SES=socioeconomic status, 95% CI = 95% confidence interval.

There were no significant differences between the children with and without objective nature exposure in CSHQ sum score (Model 1 p-values >0.315) or any of the objective sleep quality variables (Model 1 p-values >0.197) when children belonging to lower and higher SES groups were analysed separately. There were no significant differences between the children with and without objective nature exposure in CSHQ sum score (Model 1 p-values >0.567) or any of the objective sleep quality variables (Model 1 p-values >0.139) when boys and girls were analysed separately.

Discussion

Against the hypothesis, this study showed clearly and consistently that objectively measured continuous nature exposure was not associated either with parent-reported or with objectively measured sleep quality in 6-year-old children. Children who were attending nature-preschool and thus regularly spent more time in unspoilt natural sites during preschool days did not differ in the parent-reported sleep quality from the children who were attending typical preschool and thus spent significantly less time in nature during preschool. In more detail, children with and without nature exposure did not differ in parent-reported bedtime resistance, sleep onset delay, sleep duration, sleep anxiety, night wakings, parasomnias, sleep-disordered breathing, nor in daytime sleepiness. Nature exposure did not associate with any of the actigraphy measured objective sleep quality parameters either. Children who spend more time in nature did not have shorter sleep latency, longer total sleep time, or fewer awake moments after sleep onset, nor was their sleep efficiency better than children who spent less time in nature.

Children in the present study slept on average 8 h 27 min per night. Actigraphy measured normative sleep parameters in 24 h actigraphy measurement in Finnish 6-year-old population has reported a figure of 8 h 21 min [35]. Thus, the objective sleep duration measured in the current study was in the expected range for all the children.

Comparison to previous studies in children and youth

There are few previous studies on green environment and sleep quality in children and youth, and both positive and null findings have been reported [16–19]. The null results in this study give further support for the preliminary findings by Feng et al. who showed that green space around the house was not associated with subjectively measured sleep quality in 10–15 years old participants [17]. Together with findings by Feng et al. [17], these results suggest that green space exposure may not be a significant factor affecting children's sleep quality.

In addition, the results in the current study are not fully contrary to the studies that have reported positive associations between green exposure and sleep quality in children and youth. That is because in the studies where positive association was found, both positive and null findings were reported within one study. Reuben et al. reported positive associations in the two age groups (0–5 years and 6–12 years), but not in the third age group (13–17 years) [19]. Jimenez et al. found the positive association with only one greenery parameter (%grass) within 12- to 17-year-old teens, but not with any of the other three greenery variables (%Greenspace median, %Trees, %Plants) [18]. Sigh & Kelley reported that age was a significant factor behind sleep problems in their sample, including children from 6 years to 17 years, but no further age-specific analyses were reported, leaving it unknown if the reported positive associations were significant in all the age groups [16]. This incoherence in the findings in the previous studies, together with the clear null findings in the current study, indicates that green exposure seems not to have a univocal effect on children's sleep quality. Furthermore, the growing inconsistency in the literature may reflect the presence of some underlying factors, other than the actual green space exposure, explaining the association with greener neighbourhood and better sleep quality in children and youth in some, but not all, studies.

Indeed, it is worth pointing out that this is the first study comparing the effect of objectively measured green exposure and sleep quality in children. All the previous studies including children have used neighbourhood greenery level as the measurement of green space exposure when studying the associations between green space and sleep [16–19]. This distinct difference in green exposure measurement technique can also explain the somewhat unexpected null results in the present study. Previous studies in adults have highlighted the importance of measurement technique choice when studying the associations between green environment and sleep [21]. Triguero-Mas et al. have illustrated in their study on adults that objective green space exposure can be positively associated with sleep quality, but within the same group of participants, the general residential area-based measurement is not [36]. The results by Triguiero-Mas et al. give further support to the hypothesis that greenness level in the neighbourhood may be reflecting some other phenomenon than objective time spent in a green environment, also used in the present study.

Finally, it is possible that there has been positive publication bias towards reporting the hypothesised positive associations between green environment exposure and better sleep quality. Therefore, it is very important to publish also null findings from well-designed case–control studies [37].

Comparison to the studies in adults

The associations between green environment exposure and sleep quality in adults have been more coherent than the existing studies in children. Out of 11 studies on adults, 10 reported that access or actual visit to a green environment was associated with better sleep quality [13]. The findings in this study, together with the previous study by Feng et al. [17] suggest that green environment may not have similar positive effects on children's sleep as have been shown in the case of adults' sleep quality.

This study does not give straight answers why the green environment exposure seems to have different effects on children's sleep from those it has on adults'. However, the null results from this study distinctly underline the importance of taking the children's age into account when drawing conclusions and generalisations on the effects that exposure to a green environment has on sleep quality in the general population.

It can be speculated that the null findings in the present study may be partly explained by significant differences in children's sleep architecture or need for sleep, compared to teenagers and adults [14,15]. Children need more sleep, the amount of sleep spindles (a specific pattern of brain waves that occurs during sleep) and slow-wave sleep are naturally higher, and normal good-quality sleep includes more awakenings during the nights in younger than older children [38–40]. Alternatively, there is also evidence that road traffic noise affects children's perceived sleep quality less than it does the sleep of adults [41]. Thus, it is possible, yet still only speculative, that children's sleep quality may be less susceptible to environmental influences, such as nature exposure, than adult's sleep is.

And third, the differences on the effects that exposure to a green environment has on adults' and children's sleep quality may be driven by a divergence in perceived stress or physiological differences in stress reactions between children and adults [42,43]. Green environments have been shown to improve sleep quality in adults by buffering the adverse effects that perceived stress has on sleep quality [44]. So, as the stress reactions differ between children and adults [43], the stress-buffering mechanisms of green environments do not necessarily work in the same way for children as they do for adults. Further studies are needed to explore these hypotheses.

Nature exposure and sleep quality in children with different backgrounds

The second aim of the present study was to explore the moderating effects of SES and sex on the associations between green environment exposure and sleep quality in children. The results showed that neither SES nor sex moderated the association between green exposure and sleep quality. Both subjectively and objectively measured sleep quality was as good for boys and girls and children in lower and higher SES groups. These null findings do not support the preliminary finding by Jimenez et al., who reported that SES can modify the association between greenery and sleep quality in teenagers [18]. Rather, against the second hypothesis, green space exposure did not have more beneficial effects on children's sleep quality in either the higher SES group or in the lower SES group, within the group of 6-year-old children.

It is worth pointing out that, as the sleep quality of the children with regular objective nature exposure did not differ from the sleep quality of the children without objective nature exposure, the study results indicate that continuous nature exposure in preschool age children does not seem to impair children's sleep quality either. The sleep quality was as good for children who spent on average 13.1 h/week in nature during the preschool year, as it was for the children who spent most of the preschool hours inside the preschool building or in the built playgrounds next to preschool. Nature exposure has been shown to have a wide range of other positive effects on children's health in previous studies. It is associated, e.g. with boosted microbial diversity and immune regulation [45], better emotional well-being [12] and cognitive skills, and fewer behavioural problems [9], and higher physical activity and active play [46,47]. Thus, as a result, this study with its null findings did not find any reasons related to children's sleep quality why municipalities should not be encouraged to offer children regular nature exposure as part of their day care and preschool activities. This conclusion applies regardless of the children's socio-economic status or sex.

Strengths, limitations, and suggestion for further studies

This study has several strengths. This study is the first investigating the associations between children's green environment exposure and sleep quality, using objectively measured and continuous green environment exposure. In addition, sleep quality was measured using both objective and parent-reported multidimensional sleep quality questionnaire and possible moderating effects were explored.

This study also has some limitations. First, this is a correlational study, and it does not shed light on the mechanisms behind nature exposure and sleep quality. Further studies with, e.g. air pollution measurements, which in some studies are shown to mediate the residential greenness effect on cognitive skills in children [48], may increase the understanding of possible mechanisms linking green environment exposure and sleep quality. Second, the objective sleep quality was estimated using movement-based actigraphy measurement. Movement-based measurements cannot, however, be used to evaluate more detailed sleep architecture, e.g. sleep stages [49,50]. Further studies using polysomnography would be needed to explore the effects that green environment exposure may have on sleep stages or other EEG-based sleep quality measures both in adults and children.

Conclusions

This is the first study to show that objectively measured nature exposure is not associated either with parent-reported nor with objectively measured sleep quality in 6-year-old children. The null results from this study underline the importance of taking age into account when drawing conclusions and generalisations on the effects that the exposure to green environment has on sleep quality in population level. These results point out that green environment exposure may not serve as a potential environmental intervention to increase sleep quality in children.

Acknowledgments

I want to thank all the children and parents attending the study and the preschool teachers and managers for helping to organise the data collection. I am grateful to Pasi Hautala for his effort in data collection.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

Child and Nature Foundation, the Finnish Society of Forest Science, and the Ella and Georg Ehrnrooth Foundation. The funders have not had any role in the choice of the research project; design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Authorship confirmation statement

Katri Savolainen is responsible for the study design, data collection, data analysis, and writing of the manuscript. The work described has not previously been published elsewhere.

Geolocation information

Finland

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