Educational Psychology Review (2022) 34:1217–1254
https://doi.org/10.1007/s10648-022-09658-5

REVIEW ARTICLE

Effects of Nature (Greenspace) on Cognitive Functioning in School Children and Adolescents: a Systematic Review

Dianne A. Vella-Brodrick[1] · **Krystyna Gilowska**[1]

Accepted: 11 January 2022 / Published online: 19 March 2022

Abstract

There is growing interest in understanding the extent to which natural environments can influence learning particularly in school contexts. Nature has the potential to relieve cognitive overload, reduce stress and increase wellbeing—all factors that are conducive to learning. This paper provides a PRISMA-guided systematic review of the literature examining the effects of nature interventions on the cognitive functioning of young people aged 5 to 18 years. Examples of nature interventions include outdoor learning, green playgrounds, walks in nature, plants in classrooms and nature views from classroom windows. These can vary in duration and level of interaction (passive or active). Experimental and quasi-experimental studies with comparison groups that employed standardized cognitive measures were selected, yielding 12 studies from 11 papers. Included studies were rated as being of high (n = 10) or moderate quality (n = 2) and most involved short-term nature interventions. Results provide substantial support for cognitive benefits of nature interventions regarding selective attention, sustained attention and working memory. Underlying mechanisms for the benefits were also explored, including enhanced wellbeing, cognitive restoration and stress reduction—all likely to be contributors to the nature-cognition relationship. The cognitive effects of nature interventions were also examined according to age and school level with some differences evident. Findings from this systematic review show promise that providing young people with opportunities to connect with nature, particularly in educational settings, can be conducive to enhanced cognitive functioning. Schools are well placed to provide much needed 'green' educational settings and experiences to assist with relieving cognitive overload and stress and to optimize wellbeing and learning.

Keywords Cognitive functioning · Nature · Greenspace · Learning · Children · Adolescence

✉ Dianne A. Vella-Brodrick
dianne.vella-brodrick@unimelb.edu.au

Extended author information available on the last page of the article

Introduction

The pressure of modern-day westernized living involving technology, high-rise buildings, traffic congestion and pollution is taking a toll on society. These lifestyle changes have led to reduced opportunities for interacting with nature (Hartig et al., 2014) and a fast-paced lifestyle that can be psychologically draining. Subsequently health and well-being are compromised as evidenced by escalating rates of mental illness (Blake et al., 2018; Michaelson et al., 2020; Vancampfort et al., 2018). In an attempt to reduce fatigue and improve well-being, research attention has turned to the potential healing effects of nature (Capaldi et al, 2015; Diaz et al., 2015; Hartig et al., 2014).

Nature or natural environments are broadly defined as including living plants and animals, geological processes and weather. Nature exposure typically involves connecting with 'green' and 'blue' spaces including park land, forests, plants, the ocean and other natural waterways such as rivers and lakes. These can vary substantially in exposure time (from minutes to weeks and even years), as well as the extent to which nature is the core of the activity rather than simply in the background (Norwood et al., 2019). For example, nature interventions can include going for a walk amidst nature for 30 min, right through to creating a school garden which can last months or years. Multiple theories have been presented to explain the relationship between nature and different aspects of health. The Biophilia hypothesis (Urlich, 1983) posits that individuals are innately driven to affiliate with nature for survival and psychological restoration. When a connection with nature occurs, there is an opportunity for cognitive capacities to be relieved and well-being to be strengthened. The Attention Restoration Theory (ART; Kaplan, 1995) asserts that elements of the natural environment elicit a soft fascination from individuals that can release the need for relentless goal-directed attentional processes often associated with immersion in built environments and subsequently provides cognitive restoration. The Stress Reduction Theory (Ulrich, 1983; Ulrich et al., 1991) focuses on physiological responses to demonstrate that a reduction in stress induced by the natural environment can, in turn, enhance cognition. These theoretical perspectives offer a common theme of restoration through enhancing well-being by reducing mental fatigue or stress and are consistent with Wilson's concept of 'biophilia' (1984). This suggests that exposure to nature can be helpful in learning environments where cognitive functioning is fundamental. It is the broad aim of this paper to undertake a systematic review of high-quality studies examining the effects of nature (greenspace) on the cognitive functioning of school children and adolescents. This will include a broad range of passive and active nature interventions, of varying duration, that are common in school settings. This will provide insights into whether specific theoretical perspectives are most relevant for particular types of interventions (e.g., short term or active).

There has been a keen interest in exploring the extent to which children and young people connect with nature, value nature and benefit from nature (e.g., Barrable & Booth, 2020; Roberts et al. (2020). This in part stems from concern about

the rising rate of children growing up in urban environments and missing out on time spent outdoors in the natural environment (Weeland et al., 2019). Children have been identified as a population group with specific risks and needs relating to attention, self-regulation as well as physical and cognitive development (Roberts et al., 2020). The role of nature in assisting young people with these issues has preliminary empirical support, albeit with more diverse samples (Hartig et al, 2014) such as with older adults for memory enhancement (Astell-Burt & Feng, 2020). This has prompted interest in understanding how nature exposure can influence children's cognitive development and learning particularly in school environments. For example, consistent with ART, it is plausible that exposure to nature can help children to replenish depleted cognitive resources resulting from information overload. An attraction to nature can trigger 'soft' (effortless) fascination, relieve fatigue and aid psychological replenishing. In support of this, van den Berg et al. (2016) found that university students and staff who viewed 40 images of natural and built scenes and rated these on complexity and restorative quality (fascination, beauty, relaxation and positive affect) recorded longer viewing times for the nature scenes—consistent with greater fascination with nature—and rated them as more restorative than built scenes.

Most of the empirical studies on nature are correlational designs. For example, Flouri (2019) examined the relationship between neighborhood greenspace and spatial working memory for 4,758 children aged 11 years living in urban areas of England. They found that less neighborhood greenspace (measured by satellite imagery) was related to poorer spatial working memory for these children. A study by Li et al., (2019) examined the relationship between tree cover density proximal to schools and academic performance for 624 high school students. They found that tree cover density in school surroundings was positively associated with academic performance (measured using Illinois Report Cards, American College Test scores and graduation rates). A study including 101 public high schools in Michigan examined whether nature exposure—nature views from school buildings, vegetation levels on campus and the potential for students to access this vegetation—was positively related to academic performance (e.g., Educational Assessment Program test and graduation rates) and inversely related to antisocial behaviors (Matsuoka, 2010). They found that landscapes of mowed grass and parking lots were associated with poorer student performance, whereas landscapes composed primarily of trees and shrubs were correlated with favorable academic performance. With few exceptions (e.g., Markevych et al., 2019), the majority of studies have found a positive relationship between nature exposure and cognitive functioning for children. In addition, learning in greenspace or viewing nature from a classroom has also been associated with reduced heart rate and cortisol levels (Dettweiler et al., 2017; Li & Sullivan, 2016). These favorable findings also extend to longitudinal studies whereby greater exposure to residential surrounding greenspace over one's life, particularly in childhood, was associated with enhanced cognitive functioning and brain density (e.g., Dadvand et al., 2015).

A limitation of correlational studies is that causal relationships cannot be established, nor do they enable a clear understanding of the factors that influence the beneficial effects of nature on cognitive functioning. Kuo et al. (2019) examined some

of these influential factors for enhancing cognitive functioning in learning environments and identified improved self-discipline, heightened motivation, enjoyment and engagement, as well as increased physical activity and fitness. They also noted some indirect effects of nature on learners such as the calm, quiet and safe contexts often associated with nature, which then facilitate warmer and cooperative social interactions and self-directed creative play. They also proposed the notion of a synergistic effect of the numerous processes underlying the nature-learning connection. For example, nature can simultaneously increase concentration, engagement and self-discipline to enhance learning. Although Kuo et al., (2019) provide (limited) empirical support for each of these processes, they note concerns relating to the poor-quality studies and over-generalization of results in this field.

The interest of this systematic review lies in the population of school children and since this group spans a long time period, it is important to examine how nature affects children at all stages of their development. Neighborhood greenness can play an important role in cognitive development starting from the very early stages of life (Dadvand et al., 2018; Liao et al., 2019) and continuing through to later stages of childhood (Flouri, et al., 2019; Lee, et al., 2019). Dadvand et al. (2018) reported long-term exposure to greenness early in child development to be associated with beneficial structural changes in the brain. Liao et al. (2019) observed that exposure to neighborhood greenspace is associated with better early childhood neurodevelopment for those up to 2 years of age including prenatals. Mason et.al. (2021) examined the impact of short-term (from 10 to 90 min) passive nature exposure on cognitive functioning in primary, secondary and tertiary students. They found that 12 out of 14 studies reported restorative effects of greenspace for attention and working memory for all education sectors. The authors suggest that different mechanisms may be involved in long-term nature exposures, and hence, this distinction warrants further investigation.

Some researchers have examined age differences in the relationship between greenspace and cognitive functioning. For example, Lee, et al., (2019) included 6–18 year old children in their study and found that both the younger and older groups showed inverse relationship with greenness and attention problems, indicating that nature may benefit children throughout their development. In a longitudinal study, Reuben et al. (2019) observed associations between greenspace exposure and cognitive performance across all ages. Children were assessed on fluid and crystalized intellectual performance at ages 5, 12 and 18. After adjusting for socioeconomic status, greenspace exposure predicted longitudinal benefits for fluid cognitive ability among 5 year-old children. These findings add to the body of research on the importance of nature in early brain development.

Experimental studies with children are emerging but these generally have weak study designs, include short-term nature exposure, or focus on specific samples. For example, a within sample study comprised 17 students aged 7–12 years diagnosed with ADHD (Faber et al., 2009). Each student completed three walks, one week apart (and in random order). One walk was in a city park and the other two walks in well-kept urban locations (downtown and neighborhood). Performance on a Digit Span Backward task was found to be better after the park walk relative to the urban walks. These results are promising, but the extent to which these findings apply to general student populations

is unknown. More recently, reviews and meta-analyses on the effects of nature on desirable psychological and health outcomes have been published and include mostly randomized controlled trials with general samples (Stevenson, et al., 2018), including those with samples of children and adolescents (Mygind et al., 2019; Roberts et al., 2020). For example, a systematic review by Vanaken and Danckaerts (2018) included 21 studies examining the impact of greenspace on children and adolescents' mental health. They concluded that the evidence is consistent in demonstrating the favorable influence of exposure to greenspace on emotional and behavioral issues such as inattention and hyperactivity. A mini review of nature connection interventions for children was also published with the aim of identifying themes and trends (Barrable & Booth, 2020). The authors also noted poor study quality and they proposed guidelines for future work to strengthen the quality of evidence collected by researchers.

Some age differences in level of nature connection have been reported between younger children (10–12 years) compared with adolescents (13–15 years), with younger age groups reporting higher levels (Braun & Dierkes, 2017). However, no firm conclusions can be drawn as work examining nature exposure and cognitive outcomes with children is scarce. More research is needed to collate the findings from well-designed experimental studies to better understand the effects of nature on children and adolescents' cognitive capacity in school settings and their underlying mechanisms.

The main purpose of this review is to examine evidence of a causal relationship of nature exposure on cognitive functioning for the population of school children and adolescents in a variety of settings. Specifically, we review studies of diverse time exposures, from a few minutes to months and years, to capture any short-term benefits for attentional processes, as well as those for longer-term benefits like academic performance. Therefore, our definition of nature exposure was intentionally broad and could include activities where nature plays a background role, like passive viewing of the natural environment while sitting in a classroom or walking in a park or it might include activities where nature plays an active role like in outdoor gardening lessons.

More specifically this review will: (1) systematically evaluate the recent body of experimental and quasi-experimental studies examining the effects of nature (greenspace) on cognitive functioning in children and adolescents; (2) investigate the underlying processes involved in possible effects of nature on cognitive performance as well as consider the adequacy of different theoretical models to explain any effects; and (3) examine whether the effects of nature exposure differ according to age. We will also explore the duration and type of nature intervention (active or passive) to determine whether these intervention characteristics influence outcomes.

Method

Literature Search and Eligibility Criteria

An a priori protocol was designed and registered with PROSPERO (registration number: CRD42021214826). The checklist of the Preferred Reporting Items for

Systematic Reviews and Meta-Analyses (PRISMA) was applied to guide the systematic review process and began with the PICOS process to develop our main research question and to determine appropriate search terms. A PICOS structured question was formulated based on the population, intervention and outcome of interest and was: What are the effects of nature (greenspace) on cognitive functioning for school aged children and adolescents? Key components included nature exposure interventions examining cognitive outcomes, focus on school aged children, and the inclusion of high-quality studies employing experimental and quasi experimental research designs. For each component, relevant search terms were identified and then converted to keywords (see Table 1). The various search queries were based on a combination of keywords.

Three types of keywords targeted papers on nature or greenspace environment combined with cognitive outcomes, and school children population. An example of a search for the Effect of Nature on Cognitive Processes in School Children in Scopus is: ((TITLE-ABS-KEY (“school environment” OR child* OR “school landscape*” OR childhood OR pupil* OR "high-school student*")) AND (TITLE-ABS-KEY (“green break” OR “green area” OR “view* of nature” OR “nature exposure” OR “nature walk” OR “exposure* to nature” OR outdoor* OR greening OR greenspace OR greenness))) AND (TITLE-ABS-KEY (“restorative effect” OR “psychological recovery” OR “effect* on attention” OR “executive function*”OR “cognitive restoration” OR attention* OR cognitive OR "mental fatigue")).

Study selection criteria were: (a) the research study was written in English; (b) the study design was experimental or quasi experimental (e.g., participants or class of students randomly assigned to a group, pre- and post-assessments, comparison group or controlled trials); (c) exposure to nature included parks, school playgrounds, neighborhood green areas, nature views from the window or inclusion of plants inside a room; (d) nature exposure was based on expert assessment or described in detail and/or a picture was provided and/or validated questionnaire methods; (e) the study reported a measure of cognitive functioning using

Table 1 Development of research question and search strategy based on PICOS

PICOS	Concepts	Keywords/Inclusion Criteria
P (Participants)	School Children	school environment OR child* OR school landscape* OR childhood OR pupil*
I (Intervention)	Nature Exposure	green break OR green area OR view* of nature OR nature exposure OR nature walk OR exposure* to nature OR outdoor* OR greening OR greenspace
C (Comparison)	Urban, Classroom	urban walk, classroom
O (Outcome of interest)	Enhanced Cognitive Functioning	restorative effect OR psychological recovery OR effect on attention OR executive function* OR cognitive restoration OR attention OR cognitive
S (Study Design)	Comparison Group	experimental OR quasi-experimental OR RTC

standardized instruments (academic records, cognitive performance tests); (f) the study focused on school children and adolescents between 5 to 18 years of age; (g) no restriction on publication date was given. Studies were excluded if they: (a) were descriptive, observational, or a case study with no pre-/post-treatment design; (b) did not include an objective description of greenspace, or, in case of a subjective description, if there was no standardized or expert assessment of greenspace; (c) focused on children during the prenatal period or pre-school children.

The initial database searches were conducted between March and May, 2020 and updated regularly with the final update in May 2021. They were run on ELSEVIER and EBSCOhost engines through the following databases: Scopus, PubMed, Academic Search Complete, CINAHL Complete, Education Research Complete, ERIC, SocINDEX with Full Text and Urban Studies Abstracts. A total of 1393 journal papers were found, as presented in Fig. 1. In addition to the database searches, an

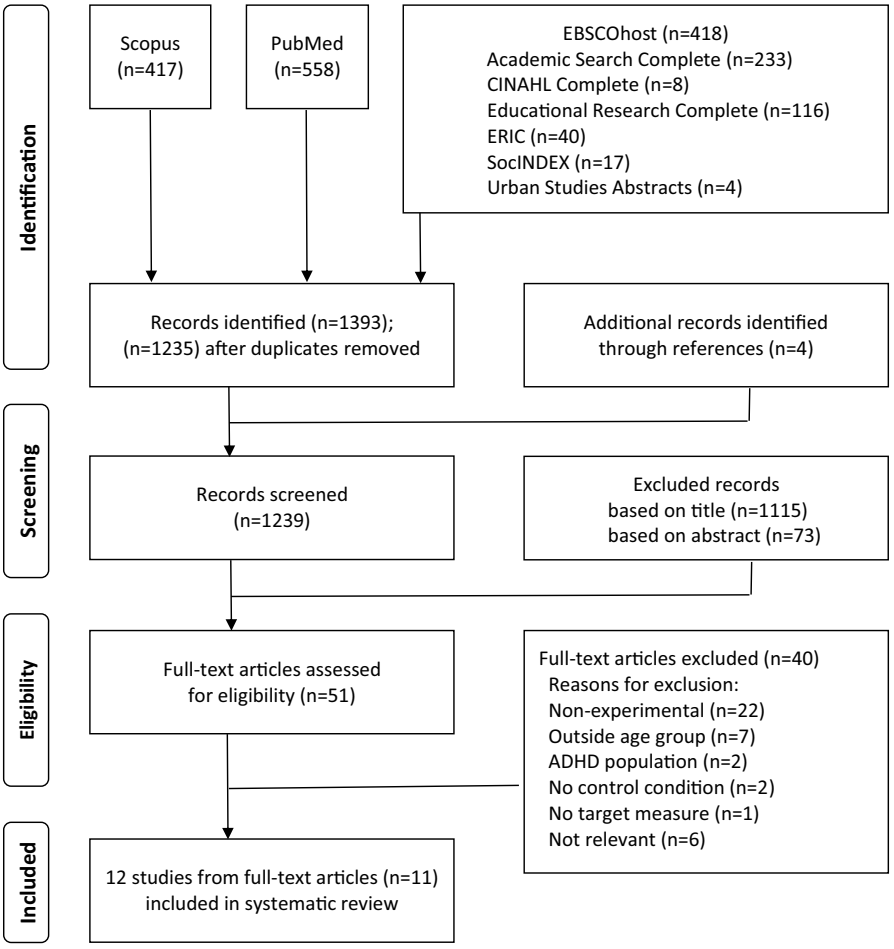

Fig. 1 PRISMA flow diagram

ancestry search that checked reference lists of key papers, and a hand search of relevant journals and grey literature were also conducted to ensure all relevant works, including unpublished but publicly available works and dissertations were included in the review. Four additional studies were identified based on reference lists of key papers. All duplicates were removed, which reduced the results to 1235.

The screening process started with removing irrelevant papers. Articles were first excluded based on titles (n = 1115), and the remaining articles were screened based on abstracts. Subsequently, the title-abstract screening process resulted in 51 articles to go through to the next stage of full-article review. The full texts of the remaining studies were carefully evaluated by both authors according to the exclusion–inclusion criteria. Eleven papers comprising 12 studies were selected for the systematic review. Reasons for the exclusions are presented in the PRISMA flowchart (Fig. 1).

The following information was extracted from the selected studies: author, year of publication, country, research focus or question, theoretical model, sample, measures, study design, intervention/comparison group and findings. See Table 2.

Quality Appraisal of Studies

An appraisal of the quality of studies to be included in the review was based on the Effective Public Health Practice Project Quality Assessment Tool (EPHPP) for Quantitative Studies (2010). The EPHPP has been shown to have robust psychometric properties and is suitable for systematic reviews of effectiveness (Deeks et al., 2003; Jackson & Waters, 2005; Thomas et al., 2004). The EPHPP assesses study quality in six domains (selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts), which can be rated as strong (1 point), moderate (2 points) or weak (3 points) according to a standardized guide and dictionary. The overall rating of study quality can also be classified as strong, moderate, or weak by averaging the scores for the six domain ratings. The two authors independently appraised the quality of each study by using the checklists included in the EPHPP manual. In the occasional case of differing ratings between the reviewers, each explained their reasons for their selection and then for any remaining discrepancies, scores were averaged across the two raters.

Results

Study Characteristics

A total of 12 studies from 11 journal articles were selected for inclusion in the review. All studies were published between 2014 and 2019 and came mainly from Europe (75%). Two were from the USA and one study came from Canada. As presented in Table 2, the studies selected were all experimental or quasi experimental designs but varied in terms of population characteristics, the nature intervention examined and the methods used to assess cognitive outcomes.

Table 2 Characteristics of studies selected for systematic review

Author, Country	Study Design	n	Sample Characteristics	Intervention	Assessment Time Points	Data Source, Outcome	Main Findings
Amicone et al. (2018), (Study 1), Rome	Quasi-experiment - W	82	Primary public school children, Urban, middle class; 48% female; Mage = 10.1 years	School garden vs built school courtyard; Standardized team play; (30 min)	Immediate post intervention	The Bells Test; (+) Digit Span Forward; (+) Digit Span Backward; (+) Go/No-Go test; (-)	Increase in sustained and selective attention, working memory but not impulse control
Amicone et al. (2018), (Study 2), Rome	Quasi-experiment - B, semi-RCT	36	Primary public school children, Urban, middle class; 47% female; Mage = 10.8 years	School garden vs built school courtyard; Free play; (30 min)	Immediate post intervention	The Bells Test; (+)	Increase in sustained and selective attention
Fägerstam and Blom (2013), Sweden	Quasi-experiment - B	85	High school students; Urban school; % female NR; Age = 13–15 years	Six outdoor lessons in grassed wooded areas vs. mostly indoor lessons with two outdoor lessons; (lessons 60 min each over 8 weeks)	5 months interview and 6 months knowledge test follow-ups	Essay-type question about the biology course content knowledge; (+) for 7 graders (-) for 8 graders(3)	(1) Higher degree of long-term knowledge retention for outdoor classes for 7 graders (2) More vivid descriptions of activities No improvement in understanding of biology
Greenwood and Gatersleben (2016), UK	RCT—B	120	High school students; South West London 55% female;	School grassed area with trees, shrubs, flowers vs. small room with no view of nature; time alone vs. with peer vs mobile phone game; (20 min)	Immediate post intervention	Necker Cube Pattern Control Task (number of reversals); (+)	Better concentration after a break in natural environment vs. indoor environment, especially when being with a friend

Table 2 (continued)

Author, Country	Study Design	n	Sample Characteristics	Intervention	Assessment Time Points	Data Source, Outcome	Main Findings
Johnson et al. (2019), Canada	Quasi-experiment - B, semi-RCT	71	Children; Halifax urban area; 55% female (experimental) 58% female (control) Age = 8–15 years	Green forested trail vs. built urban area; Walk in small groups of unknown children with a guardian; (30 min)	Immediate post intervention	Combined Attention Systems Test (CAST); Orienting (+) Alerting (+) Others (-)	Results support effects of nature on endogenous attention: Alerting and Orienting, but not on any of the measures of exogenous attention
Li and Sullivan (2016), USA	RCT—B	94	High public school students; urban and rural central Illinois, 56.4% female; NR	Green landscape view vs. built space vs. no window view; Sitting in seats resting with 2 examiners in the room; (10 min)	During intervention, class activity (30 min)	Digit Span Forward & Digit Span Backward (+)	(1) Increased attention in the green view vs. no green window condition (2) Stress reduction did not mediate nature effect
Mygind et al. (2018), Denmark	Quasi-experiment - W	47	Primary school children accustomed to OE; affluent areas; 38% female;	Grassed area with trees vs. classroom environment airy or dark; Reading quietly; (60) minutes	During intervention, testing time (20 min) to be added	D2-R Test (-)	(1) No effect of nature on superior cognitive performance (2) Higher tonic vagal tone in natural environments vs. classrooms
Stevenson et al. (2019), Denmark	Quasi-experiment semi-RCT - W	33	Children from an independent school; 61% female; Age = 10–14 years	Grass fields, tracks with young pine trees, rocks, farmland, forest; vs. urban area Contemplative walk in small groups of 4–5; (30 min)	Immediate post intervention	The Attention Network Task (ANT, fish flanker task); Speed (+) Consistency (+) Executive (-)	(1) Faster, more stable responses on ANT after intervention (2) Greater number of eye fixations per minute (3) No improvements in executive attention or accuracy

Table 2 (continued)

Author, Country	Study Design	n	Sample Characteristics	Intervention	Assessment Time Points	Data Source, Outcome	Main Findings
van den Berg et al. (2017), The Netherlands	Quasi-experiment - B	170	Primary school children; non-deprived; 43% female Mage = 9 years	Green wall with living plants vs. no green wall in a classroom; Breathing exercise looking at the green wall vs. with closed eyes; (a short time)	During intervention, testing time (20 min) to be added to 2 & 4 months follow-up times	Digit Letter Substitution Test; (-) Sky Search Task; (+)	Increased selective attention in the green wall vs. with no green wall condition; No effect on processing speed
van Dijk-Wesselius et al. (2018), The Netherlands	Quasi-experiment - B, W	2031	Primary school children; moderate-to-high-urbanized areas; just over 60% female; Age = 7–11	Schoolyard with trees flowers, sand, water, grass, hills, bushes vs. paved schoolyard; Active recess time; (15 min)	Immediate post intervention to be added to 1 & 2 years follow-up times	Digit Letter Substitution Test; (+) Sky Search Task; (first follow-up-trend only, p = .08), second follow-up (+)	Positive effect of Greening of Schoolyard on processing speed and trend on selective attention after school recess at second follow-up
Wallner et al. (2018), Austria	Quasi-experiment - W	64	High school students; Chosen from 3 schools in Vienna; 50% female; Age = 16–18 years	Forest vs. large park with trees vs. small urbanized park; Walk with class children; (60 min)	Post intervention and 20 min distance to school	D2-R test (+)	Sustained/Selective attention improvement after the break in all three green spaces, especially medium park
Wells et al. (2015), USA	RCT—B	64	Primary school children; Low income, from rural to urban; Age = 6–12 (at baseline)	Raised-bed garden kit vs. no kit; 19 garden vs. indoor lessons on nutrition, plant science, and horticulture	1 & 2 years follow-up	Science knowledge measured by 7-item questionnaire on nutrition and plants (+)	Positive effect of school garden intervention on knowledge retention, especially for high fidelity garden intervention

W—within-subjects design, *B*—between-subjects design, *RCT*—randomized control trial; (+) significant positive result, (-) not significant result

Study designs included three randomized and three semi-randomized controlled trials, with most of them being between-subject designs and one a semi-randomized study adopting a within-subject design. The remaining studies were quasi-experimental (within-subject = 3, between-subject = 3). A variety of statistical analyses were applied across studies, including ANOVA, ANCOVA, t-tests and F statistics. Sample sizes were generally adequate but varied substantially across studies ranging from 33 to 3,061 participants. The methodological quality of the studies was assessed as outlined in the method section. Table 3 shows the quality ratings according to each domain of assessment and a global quality rating and classification for each study.

Ratings indicate 83% (10/12) of the studies received a classification of strong (falling within the 1.0–1.50 range) and 17% (2/12) received ratings of moderate (falling within the range of 1.51–2.50). None of the studies received a "low" classification. This signifies that the studies included in this review were generally of a high standard. The quality of studies was also examined within the specific scoring domains and revealed a tendency of bias to occur mostly in the Study Design and Blinding domains. The remaining four domains, namely the Selection Bias, Confounders, Data Collection and Withdrawals and Dropouts, have been rated as predominantly strong or having negligible chance of bias.

Study populations of the reviewed studies included children and adolescents of different age groups. Four of the studies included high-school students aged 16–18 years, and one study included groups of younger adolescents aged 13–15. School children aged 10–12 were recruited in four studies, and one study comprised a diverse group of adolescents aged between 8–15. The two remaining studies represented the youngest age group, one with participants ranging from 7 to 10 years, and the other, between 6 and 12 years. All studies included male and female participants, and overall, there was a reasonable balance of male and female participants across the selected studies.

Collectively, the selected studies operationalized nature interventions as including a variety of natural environments such as school playgrounds, parks, woodlands, school greenery and indoor environments with plants. The interventions differed in time duration, level of social and physical engagement and degree of greenery involved. Table 2 summarizes the types of nature interventions and the comparison activities used in the selected studies. In terms of time duration of interventions, eight studies used short-term nature exposures (from a few to 60 min), while four studies included long-term exposures in their designs (from 2 months to 2 years).

Various cognitive tests have been used in the selected studies as the outcome variable to capture the possible effects of nature on cognitive functioning. They represent two major groups of tests—attention tests (n = 9) and long-term memory knowledge tests (n = 2). Attention tests can be further distinguished on the basis of the cognitive domain they are mainly designed to capture, even though the cognitive domains often overlap in a test. There are four main types of attention tests evident from the selected studies: (1) working memory tests, like Digit Span Backward, demanding ability to hold and manipulate information in the short-term; (2) selective attention tests, like the Fish Flanker Task, which requires the participant to direct attention to the task while simultaneously ignoring distractors; (3) processing

Table 3 Methodological quality assessment of selected studies

Author, Year	Selection bias	Study design	Confounders	Blinding	Data collection	Withdrawals and dropouts	Global quality
Amicone et al. (2018), (Study 1)	1	2	2	2	1	1	Strong (1.5)
Amicone et al. (2018), (Study 2)	1	1	1	2	1	1	Strong (1.17)
Fägerstam and Blom (2013)	1	2	2	3	1	2	Mod (1.83)
Greenwood and Gatersleben (2016)	3	1	1	1	1	1	Strong (1.33)
Johnson et al. (2019)	1	2	1	2	1	1	Strong (1.33)
Li and Sullivan (2016)	1	1	1	2	1	1	Strong (1.17)
Mygind et al. (2018)	2	2	1	2	1	1	Strong (1.5)
Stevenson et al. (2019)	2	2	1	2	1	1	Strong (1.5)
van den Berg et al. (2017)	1	2	2	2	1	1	Strong (1.5)
van Dijk- Wesselius et al. (2018)	1	2	1	2	1	1	Strong (1.33)
Wallner et al. (2018)	2	2	1	2	1	2	Mod (1. 67)
Wells et al. (2015)	2	1	1	2	1	2	Strong (1.5)

Domain Ratings: 1 = Strong, 2 = Moderate, 3 = Weak

speed test, like the Digit Letter Substitution Test, the main goal of which is to process as many items as possible in limited time periods; (4) and the Go/No-Go test intended to measure impulse control (see Appendix Table 7).

Effectiveness of the Nature Interventions

Studies included in this review enabled us to investigate nature interventions on cognitive functioning across different attentional domains as well as on long-term memory knowledge acquisition. First, we will present the findings from the attention tests in four sections: (1) working memory tests, (2) selective attention tests also including tests with varying degrees of sustained/selective attention tests, (3) processing speed and (4) impulse control tests. Then we will present the findings from the long-term memory knowledge tests.

Attention Tests

Most studies in our review applied short-term nature exposures to find possible causal effects on attentional processing. These studies were more consistently able to report attentional processing benefits than studies that used long-term nature exposures in their designs.

Working Memory

Two studies (Amicone et al., 2018; Li & Sullivan, 2016) found a significant positive effect of nature on working memory performance in middle-class public school children in Rome and in both urban and rural high-school students in central Illinois public schools, respectively. Both studies used Digit Span Forward and Digit Span Backward, but the tasks differed on whether participants were to write the digits down (Amicone et al., 2018) or to repeat them verbally (Li & Sullivan, 2016). The Rome study used 30 min active play in a green school playground, while the Illinois study used a window view onto green landscape with two examiners in the room where the participants were seated and resting for 10 min. These studies indicate that relative to control conditions, two different nature interventions (one immersive and one passive) involving different age groups can improve cognitive performance that relies on the ability to hold and manipulate information in short-term (working) memory.

Selective Attention and Sustained/Selective Attention

The main common task in tests designed to measure selective attention is to direct attention towards a target while simultaneously ignoring distractors. Most studies (n = 9) in our systematic review have been designed to measure selective attention; however, they have used five different tests for this purpose. In particular, Combined Attention Systems Test (CAST) and the Attention Network Task (ANT) tests are similar measures based on the fish tanker test where the target fish is presented

facing left or right and flanked by other fish pointing in congruent or incongruent directions, as a cue or distractor. The task requires respondents to indicate the correct direction of the target fish. Other tests like the Necker Task are also used as measures of selective attention but are notably dependent on visual processing. Likewise, The Sky Search and D-2R tests also rely on visual resources to sustain attention. Hence, caution is required when explaining the causal effect of nature on selective attention as visual processing can be a confounding factor.

Two studies (Johnson et al., 2019 and Stevenson et al., 2019) using similar computer attention tests based on the fish flanker task, reported a significant positive effect on selective attention performance after a 30-min walk in a natural environment with trees. Johnson et al. (2019) found a small positive effect with Canadian children of mixed age between 8 to 15 years old after walking through a forested trail in Shrubie Park. Stevenson et al. (2019) found a positive effect for speed and stability of responses, in children aged 10–14 years recruited from an independent school in Denmark, after walking through rolling grass fields with young pine trees and rocks, farmland and forest. However, no improvement in *executive* attention was found in this study.

Two studies (Amicone et al., 2018, studies 1 & 2) found natural environments, designed as structured green playtime and free play in a school garden respectively, exert a significant positive effect on attention control as measured by the Bells Test in primary public school middle-class children in Rome. The Bells test contains four different sheets with small black drawings of different symbols and the task requires respondents to mark all 35 bells embedded within 280 different distracting symbols. The test is relevant to selective attention control but also requires visual scanning. Greenwood and Gatersleben, (2016) also found a positive significant effect on selective attention for high school students of South West London after spending time in the school grassed area with trees, shrubs and flowers for 20 min. They used the Necker Cube Pattern Control Task to measure attention control.

Impulse Control

One study used an impulse control attention test, as measured by Go/No-Go task, to investigate impulse control after green structured play (Amicone et al., 2018). They found no significant positive effect in middle-class public school children in Rome after playtime in a school garden compared with a built playground.

Regarding Sustained/Selective Attention, four studies reported mixed findings derived from the D2-R—Letter Cancellation Task and Sky Search attention tests. The tests are used to measure selective attention but at the same time they require sustained attention for performance. Each test, respectively, presents rows of similar pictures or letters for the participants to visually scan to spot differences. Nature, designed as the living plants classroom wall, has been found to have a significantly positive effect on sustained/selective attention as measured by the Sky Task (van den Berg et al., 2017) in Dutch primary school children. However, the same attention test used in a longitudinal study by van Dijk-Wesselius et al. (2018), for a similar population in the Netherlands, did not yield significant results until after two years

of green schoolyard exposure at the second follow-up, reporting only a positive trend at the first follow-up. These two studies differ from previous research in their aim to explore the effects of long-term nature exposures on cognition, rather than short-term ones.

Similar to the long-term studies, Sustained/Selective Attention, as measured by the D2-R—Letter Cancellation Task, was not found to be consistently and positively influenced by short-term nature exposure, indicating that perhaps this cognitive domain may not necessarily benefit from exposure to greenspace, irrespective of the duration of exposure. One study (Wallner et al., 2018) reported a significant positive effect after a 60-min break in a green park or forest relative to a small urban park in high school students in Vienna, but no effect was found in younger affluent Danish children 10–12 years old, after being exposed to a grassed area with trees compared with a classroom environment while reading quietly for 60 min (Mygind et al., 2018).

Processing Speed

Mixed findings have also been reported for long-term nature exposure studies examining processing speed as measured by the Digit Letter Substitution test (van Dijk-Wesselius et al., 2018; van den Berg et al., 2017). For the task participants were instructed to convert randomly ordered digits to letters according to a key and to do so within short periods of time. No significant positive effect was found on processing speed in the living plants classroom wall exposure study in Dutch primary school children (van den Berg et al., 2017). However, a significant positive effect was reported in the Greening of School study in Dutch school children aged 7–11 years (van Dijk-Wesselius et al., 2018). Again, these findings may reflect true inconsistency of nature exposure on processing speed, or the difficulty in establishing causal effect for long-term exposure studies.

Long-term Memory—Knowledge Acquisition

Only two studies in our review applied long-term nature exposures to find possible causal effects on long-term knowledge acquisition, and they were inconsistent in their ability to produce favorable outcomes. Wells et al. (2015) found school gardens to be beneficial for enhanced science knowledge, as compared to classes with no garden intervention in American children aged 6–12 years from low-income rural, suburban and urban schools. In addition to the "knowledge of plant science and nutritional science test," they also measured the degree of intervention fidelity, which provided dose-based data to further support the findings. Accordingly, classes that reported the greatest increases in their science knowledge, by 0.78 on average, were the ones receiving higher dosages of the garden intervention.

Fägerstam and Blom (2013) compared outdoor with indoor learning in an urban high school environment with a traditional curriculum. They measured long-term knowledge acquisition by an essay-type question examining the biology course content, (i.e., on knowledge of ecology and classification), and further assessed the

academic outcomes by a semi-structured interview. They found greater long-term knowledge retention for outdoor compared with indoor classes for 7th graders. However, no significant effects of nature were found for 8th graders. Additional interview data analysis revealed that, overall, intervention participants reported more vivid descriptions of class activities, which were interpreted as coming from higher positive emotional involvement.

Underlying Mechanisms

The second aim of this review is to investigate potential underlying mechanisms of the nature-cognitive performance relationship. Studies designed to demonstrate the effect of nature on cognitive functioning can also provide additional support for the foundational theories and can help to illuminate underlying mechanisms. These studies may also report beneficial effects of nature on some aspects of well-being that could function as mediators for enhanced cognitive outcomes. However, a full analysis of how nature produces beneficial effects would require more targeted and comprehensive work addressing a broad range of mediators to propose a theory. None of our studies have fully investigated the nature-cognition mechanisms specifically in relation to structured physical activity and social interactions; therefore, with regard to our second goal, we take an exploratory approach.

Our systematic review has captured studies that represent three types of theoretical perspectives, each of which proposes a distinctive but complementary explanation for why nature could benefit cognitive functioning and uses a corresponding measurement approach from which to examine the specific theory (see Tables 4, 5 and 6). Thus, different psychological scales and physiological instruments have been employed in the selected studies to uncover possible underlying mechanisms for the beneficial effects of nature.

In this systematic review some studies reporting positive findings point to perceived restorativeness as an explanation, typically assessed either by the Perceived Restorativeness Scale (PRS) or a self-assessed question/questions. For example, Amicone et al., (2018) in studies 1 and 2 reported beneficial findings and noted that children perceived natural environments to be more restorative as measured by the Perceived Restorativeness Scale. This finding supports the restorative process of nature exposure, particularly when contrasted with immersion in the built environment. Consistent with ART, these two studies demonstrated that restorative processes can occur in nature irrespective of how children choose to engage with it, whether in a structured game or free-play.

Stevenson et al. (2019) reported faster and more stable responses on the Attention Network Task after a green walk relative to an urban walk. They did not however, find any significant difference on executive (goal-directed) performance which is central to ART. Stevenson et al. also used a mobile eye-tracker instrument to measure distribution of eye gaze during exposures. Although for only a small sample, they provided some support for ART reporting higher rates of eye gazing during a nature walk compared to an urban walk, they proposed that through the soft fascination element of nature, participants were visually engaged and wanted to explore

Table 4 Cognitive performance and other outcomes for studies with the ART framework

Author, Year, (sub-study)	Cognitive performance measures; (Outcome)	Other measures (Outcome)	Findings
Amicone et al. (2018), (1)	The Bells Test; (+) Digit Span Forward; (+) Digit Span Backward; (+) Go/No-Go test; (-)	PRS (+)	1) Increase in sustained & selective attention, working memory but not impulse control (2) Higher scores on PRS for natural environment than built environment
Amicone et al. (2018), (2)	The Bells Test; (+)	PRS (+)	1) Increase in sustained & selective attention (2) Higher scores on PRS for natural environment than the built environment
Johnson et al. (2019)	CAST; Orienting (+) Alerting (+) Others (-)	CNS as control	(1) Improvement on two measures of endogenous attention: Alerting and Orienting, but not on any of the measures of exogenous attention (2) Worse performance after urban walk
Stevenson et al. (2019)	ANT (fish flanker task); (+)	PRS-CII as control Mobile eye tracking (+)	(1) Faster, more stable responding on ANT after nature walk vs. walk in built environment, (2) No improvements in executive attention or accuracy; (3) Natural environment perceived as being more restorative than built environment, (4) Greater number of eye fixations per minute while walking in the natural environment than built environment

PRS—Perceived Restorativeness Scale; *CAST*—Combined Attention Systems Test; *CNS*—Connectedness to Nature Scale (Mayer & Frantz, 2004); *ANT*—The Attention Network Task; (+) significant positive result, (-) not significant result

the scenery, hence the higher rates of eye-gazing, and, presumably, higher levels of restoration.

Johnson et al., (2019) provide support for ART by demonstrating a small but significant improvement on executive attention (referred to as endogenous), measured by CAST. This study found that a walk in a natural environment provided elements needed for restoration of goal-directed attention compared with a walk in an urban environment, however, this study did not include a measure of restoration. No additional support for ART was evident from the study by van den Berg et al., (2017). They provided results on self-reported ability to concentrate as well as on emotional, cognitive and social well-being. These additional measures were

administered to provide insights into the effects of a green wall in the classroom on sustained/selective processing, as measured by the Sky Search task. Although they found a significant positive effect for selective attention, no underlying mechanism could be suggested since no difference between the groups with and without a green wall was found on self-reported concentration or on well-being. The study intervention involved long-term exposure and was complex in its design. It was mixed with short-term exposure which in itself may not have been effective (i.e., resting with eyes closed for the control group might be more restful than looking at the green wall for the experimental group). Thus, the short-term effect could have interfered with the long-term exposure to the green wall. In sum it would seem that the underlying mechanisms of ART theory were best demonstrated by the studies using short-term nature exposures when mental restoration was needed.

The remaining studies come from research perspectives associated with different pathways as possible mechanisms for the restorative effect of nature on cognitive processes. They propose that other mechanisms apart from mental fatigue restoration could include stress and affect. One of these studies (Li & Sullivan, 2016) provided additional results on self-reported subjective attention and stress, measured by a Visual Analogue Scale (VAS), as well as measures on objective stress, including blood volume pulse, electrocardiography, skin conductance and body temperature. All the data were entered into regression models to provide further insight on possible factors at play to explain their main finding, that is, the effect of a green view on working memory, as measured by digit span tests. Since the analysis revealed no correlation between attention and stress changes, Li and Sullivan (2016) proposed that nature exposure was likely to have a direct impact on working memory performance rather than through the effect of a stress pathway. This study used only 10 min of exposure time, adding to the body of evidence on nature restorative capacities for attentional processes.

Wallner et al., (2018) explored psychological dimensions of well-being for positive effects of greenspaces on concentration performance measured by the D2-R test. They adopted the scale (Nitsch, 1976), which is designed to measure motivation and strain attributes for six categories (recuperation, tension/relaxation, state of mood, readiness for action, readiness for exertion, and alertness) of the Self-Condition Scale. They investigated how motivation and strain could help to explain their main findings and found that large greenspaces resulted in greater cognitive performance alongside several psychological dimensions of recuperation, tension/relaxation, mood state, readiness for action, and readiness for exertion. These dimensions are indicative of a higher degree of restorativeness, as well as psychological and physiological calming. Hence, these may be mediating factors for the effect of nature on cognition, suggesting that the key theories may be inter-connected.

Greenwood and Gatersleben (2016) reported improvement in concentration, as measured by the Necker Cube Pattern Control Task in a natural environment versus an indoor room, in three additional contexts for each condition, being alone, alone with a mobile phone, and being with a friend. They used Zuckerman's (1977) Inventory of Personal Reactions (ZIPERS) as their measure of positive affect, attentiveness, fear, sadness and anger to support their findings, and included objectively measured stress for this purpose as well. They reported a significant interaction

Table 5 Cognitive performance and other outcomes for studies with the ART and SRT framework

Author, Year, (sub-study)	Cognitive performance (Outcome)	Other measures; (Outcome)	Findings
Greenwood and Gatersleben (2016)	NCPCT (number of reversals); (+)	Heart Rate; (+) Blood Pressure; (-) ZIPPERS; Positive affect (+)	Better concentration after a break in natural environment vs indoor environment, especially in the context of being with a friend
Li and Sullivan (2016)	Digit Span Forward & Digit Span Backward (+)	VAS-self-reported attentional functioning; (+) Physiological stress; (+)	(1) Increased attention in the green view vs. with no green window condition (2) Stress reduction did not mediate the the relationship between window view and attention restoration
van den Berg et al. (2017)	Digit Letter Substitution Substitution Test; (-) Sky Search Task; (+)	Self-reported ability to concentrate; (-) Self- reported emotional state; (-)	(1) Increased selective attention in the green wall vs. with no green wall condition (2) No effect on processing speed (3) No improvement on emotional state
Wallner et al. (2018)	D2-R Test; (+)	Nitsch scale; (+)	(1) Sustained/Selective attention improvement after the break in all 3 green spaces (small urban park, medium park, forest), medium park especially (2) Well-being increased after the stay in the 3 green spaces, but a sustained effect only for the forest condition
Mygind et al.(2018)	D2-R Test; (-)	PHASIC; (+)	(1) No improvement of superior cognitive performance in the natural environments compared to the classrooms (2) Tonic vagal tone was higher in the natural than the classroom environments

NCPCT—Necker Cube Pattern Control Task; *PHASIC*—the difference between tonic and event vagal tone; (+) significant positive result, (-) not significant result

Table 6 Cognitive performance and other outcomes for studies with the Outdoor Learning (OL) and Greening of Schoolyard framework

Author, Year	Cognitive performance measures; (Outcome)	Other measures Outcome)	Findings
Fägerstam and Blom (2013)	An essay-type question on biology course content	Semi-structured interviews for cognitive and emotional dimensions (+)	(1) Higher degree of long-term knowledge retention for outdoor vs. indoor classes for 7th Graders (2) No difference in biological understanding (3) More vivid descriptions of activities
van Dijk-Wesselius et al. (2018)	Digit Letter Substitution Test; (+) Sky Search Task; (trend only, p = .08)	Appreciation of the Schoolyard; (+) PRCS; (-), (+) PQLS; (-)	(1) Positive effect of Greening of Schoolyard on processing speed and trend on selective attention after school recess at second follow-up (2) Positive impact on appreciation of the schoolyard (3) Some short-time positive impact of Social Orientation for younger children and negative impact for older children (4) Some support of greening on self- reported peer problems (5) No impact of greening on emotional functioning (6) Impact on time spent outdoors only for girls at first follow-up
Wells et al. (2015)	Science knowledge measured (7-item questionnaire on nutrition and plants)	GIF as control	Positive effect of school garden intervention on knowledge of plant science and nutritional science, especially for high fidelity garden intervention

PRCS - Perceived Restorative Components Scale; *PQLS*-Pediatric Quality of Life Scale; *GIF*- Garden Intervention Fidelity; (+) significant positive result, (-) not significant result

effect for positive affect in a natural environment compared with an indoor room. This supports a biophilic response whereby nature feels both good and familiar. In addition, Greenwood and Gatersleben (2016) analyzed the role of social relations in the nature-cognition relationship. They concluded that even though improvements on the Necker Cube Pattern Control Task were observed across all contexts in the natural environment, for this particular age group of 16–18 year olds, nature appears to be especially restorative if it is undertaken with friends.

The social aspect is also a possible mediator in a longitudinal study on greening a schoolyard (van Dijk-Wesselius et al., 2018). In the second follow-up, after two years of exposure to a green schoolyard, children reported scoring significantly better on sustained/selective attention and processing speed compared to children with paved schoolyards. Self-reported questionnaires on aspects of well-being were also analyzed alongside the main results and a green schoolyard was found to benefit social well-being. By comparison, no improvements on emotional well-being were found. Children's appreciation of the green schoolyard was suggested as an additional possible mediating factor, perhaps pointing to natural order and beauty as playing a bigger role than just purely aesthetic. As it is usually difficult to establish a direct effect of long-term nature exposure on cognitive functioning, many possible indirect mediators are possible.

Mygind et al. (2018) investigated the impact of nature on cognition in terms of the Stress Reduction Theory (Ulrich, 1983). They used tonic and phasic cardiac vagal tone for this purpose. Tonic vagal tone enables the modulation of the vagus nerve which fosters a calming effect on heart rate during rest and is linked with greater adaptability to external factors (Mygind et al., 2018). As predicted, they found that tonic vagal tone (but not event or phasic vagal tone) was higher in the natural environment than in indoor classrooms, but no significant difference was observed on the D2-R attention test in these two conditions. This increase in tonic vagal tone may lend some weight to the SRT.

Finally, the two remaining studies in our review (Fägerstam & Blom, 2013; Wells et al., 2015) align with the outdoor learning perspective—a body of research that mainly focuses on long-term knowledge acquisition rather than attentional functioning (Becker et al., 2017). Depending on the specific theory prescribing outdoor learning, studies may either attempt to explain psychological/physiological internal processes during learning out in nature or be more practical and explain in detail what aspects of the intervention appear to be most effective.

Wells et al. (2015) examined the effects of a school garden intervention on science knowledge, specifically on nutrition and plant science. A significant effect of garden lessons relative to indoor lessons, on science knowledge was found especially for interventions with high garden intervention fidelity. Fidelity was examined to provide details about how specific aspects of garden learning interventions contribute to the program's success. Wells et al. (2015) found that higher intervention fidelity involved greater dosage of outdoor garden classes as well as having more success at growing and sharing fruits and vegetables. However, the study did not provide sufficient empirical evidence on underlying mechanisms such as how longer exposure to garden lessons might affect knowledge acquisition. Another outdoor learning study (Fägerstam & Blom, 2013) investigated children's internal thoughts and emotions about the intervention using interviews, to further explain

the main findings. The outdoor group described their outdoor lessons more clearly, used content-related words and showed more enthusiastic and participatory behavior compared with the indoor group. However, only children in Year 7, and not Year 8, demonstrated a significant improvement in their content knowledge, as measured by the biology essay-type questions. Hence, there is some uncertainty about how, or if, children's emotions might contribute to the nature-cognition relationship and the significance of age on this relationship.

In sum, it would seem that the nature studies included in this review support a multitude of underlying factors influencing the nature-cognition relationship. However, the restorative factor is the one that has been most commonly tested with the use of specific self-report restoration measures such as the Perceived Restorativeness Scale. It is noteworthy however, that this measure includes items assessing dimensions such as relief from daily stressors and strains, feeling relaxed, free movement and curiosity. Hence, restoration can extend beyond cognitive relief to also include physical and psychological aspects. In particular, the increased physical activity and social interaction typically associated with outdoor learning may also be influencing factors (Becker et al., 2017). This lends weight to the possibility that multiple underlying factors might be at play potentially producing a synergistic impact as suggested by Kuo et al., (2019).

Effects of Nature interventions and the Influence of Age

The third aim of our review was to investigate possible differences of nature exposure effects on cognitive functioning for children of different age groups. Greenspace exposure does not seem to differentially effect child and adolescent cognitive functioning as it is generally beneficial for all age groups covered in this review. For high school students, however, the effect of greenspace on attentional functioning is found more consistently (Greenwood & Gatersleben, 2016; Li & Sullivan, 2016; Wallner et al., 2018) indicating that older children can benefit from a variety of nature interventions irrespective of whether it is a window view of nature, a walk in a park, or spending time playing in nature. These studies have shown that working memory, as well as selective and sustained attention, improve for high school students after green exposure, compared with urban exposures. For long-term knowledge acquisition the effect of nature produces mixed results with this older age group. Fägerstam and Blom (2013) found that outdoor lessons can improve students' knowledge retention on biology for a seventh grade group but not for the eighth graders. Wells et al., (2015) found that across a diverse age range (6–12 years) experiential garden-based lessons on nutrition, horticulture and plant science resulted in significantly better knowledge retention assessed using a multiple-choice test, relative to those who completed classroom-based lessons.

Similar patterns for attentional functioning have been found in other age groups. For younger, mostly secondary school children, there is evidence that children can benefit from nature exposure in terms of working memory as well as selected and sustained attention (Amicone et al., 2018; Johnson et al., 2019; Stevenson et al.,

2019) after a walk or play in a natural compared with urban environment. The remaining studies focusing on secondary school children (Amicone et al., 2018; Mygind et al., 2018) examined two additional attentional domains, namely, impulse control and selective/sustained attention, with an emphasis on visual scanning and processing speed, as measured by the Go/No-Go and D2-R tests, respectively. No observed significant positive effects of nature exposure were found in these studies. Finally, for the youngest group of school children (aged 7–12 years), nature exposure does not show similar patterns of effect in cognitive functioning as for middle and high school children. Had there been more experimental studies focusing on young children, perhaps a pattern could be established. Wells et al., (2015) have provided evidence that 6–12 year old children can benefit from a school garden intervention in terms of long-term knowledge retention on plant and nutritional science compared to children with no garden activity lessons. This finding adds to the body of research in nature exposure on long-term memory retention, but further work is needed since mixed results have been reported for older groups of children. With respect to attentional processes in young children, the effect of nature exposure on selective/sustained attention and information processing speed has produced mixed results (van den Berg et al., 2017; van Dijk-Wesselius et al., 2018).

Study duration

As can be seen from Appendix Table 8, most interventions used in the studies reviewed were of a short duration and focused on attentional functioning as an outcome. Five studies used immediate post-intervention designs with a time range of 20–30 min (Amicone et al. (study 1 and 2), 2018; Greenwood & Gatersleben, 2016; Johnson, et al., 2019; Stevenson, et al., 2019). These studies were most consistent in reporting positive effects of nature exposure, in particular, on selective attention, working memory, concentration, alerting, orienting and speed, with exception of impulse control (Amicone et al. (study 1), 2018), exogenous attention (Johnson, et al., 2019) and executive attention (Stevenson, et al., 2019).

The remaining short-term exposure studies used post-intervention designs and during intervention designs (10 to 60 min) (Wallner et al., 2018; Li & Sullivan, 2016; Mygind, et al. 2018). Our review supports the effectiveness of short-term nature interventions to improve attentional functioning. However, mixed results were reported on sustained/selective attention, namely, positive effects were reported by Wallner et al. (2018), and no effects were reported by Mygind et al. (2018).

Four studies in our review applied longer-term exposures in their designs (Fägerstam & Blom, 2013; Wells et al., 2015; van Dijk-Wesselius et al., 2018; van den Berg et al., 2017). Specifically, there were two experiments (Fägerstam & Blom, 2013; Wells et al., 2015) that examined whether exposure to natural environments influenced knowledge retention over longer-time periods (5 and 6 months, 1 and 2 years follow-up). Both studies examined outdoor education in school-settings. Wells et al. (2015) provided support for benefits of outdoor education in school settings for primary school children, Fägerstam and Blom (2013), however, reported benefits for 7th graders but not for 8th graders.

The remaining two studies (van Dijk-Wesselius, et al., 2018; van den Berg, et al., 2017) examined long-term nature exposure (2 and 4 months, and 1 and 2 years, respectively) on attentional functioning rather than long-term knowledge. The studies were complex in their design and provided mixed findings of nature exposure on selective attention and processing speed. For example, the green wall study (van den Berg, et al., 2017) was designed to measure attentional functioning after a short-time exposure of looking at the classroom green wall (a few minutes), just before testing. In addition, this short exposure was also combined with longer-term exposures of 2 and 4 months, accumulating during the time children were studying in the green wall classroom. So, it is difficult to disentangle short-term effects from long-term effects. Similarly, van Dijk-Wesselius, et al. (2018) used 1 and 2 years of long-term exposures to school greenery and reported beneficial effects on processing speed at the second follow-up. However, the testing was administered after school recess, again adding a short-term exposure as a possible effect.

Discussion

The primary aims of this review was to (1) systematically evaluate the body of experimental and quasi-experimental studies examining the effect of nature (greenspace) on cognitive functioning in children and adolescents; (2) to investigate the underlying processes involved in possible effects of nature on cognitive performance and to consider the adequacy of different theoretical models to explain any effects; and, finally to, (3) examine whether the effects of nature exposure differ according to age. In addition, possible differences in relation to the duration and type of nature intervention were examined. This review found that based on 12 relatively high-quality studies, there seems to be substantial evidence that exposure to nature can enhance cognitive functioning in children and adolescents. This review included an examination of a range of cognitive functions relating to attention and knowledge acquisition including working memory tests, selective attention tests (also including tests with varying degrees of sustained/selective attention tests, processing speed), impulse control tests and long-term memory (knowledge acquisition). Many positive effects were found especially across the sub-categories of working memory and sustained/selective attention. There were only three studies focusing on processing speed (n = 2) and impulse control (n = 1) and the findings of these were less favorable. These findings suggest that key cognitive processes relating primarily to attention and memory (working and long term) were enhanced following nature exposure. This was irrespective of the actual nature intervention being delivered (e.g., playing outdoors in greenspace, observing nature from a window or gardening). As all the included studies were of a high (n –10) or moderate standard (n = 2) using the EPHHP, the findings hold firm and have practical implications for learning environments with young people. Integrating nature interventions with teaching and learning practices can provide welcome cognitive relief for highly anxious young people feeling the pressures of academic performance and testing. Simply learning amidst nature and short-term nature interventions can have beneficial cognitive effects particularly for high school students.

This review also explored what the underlying mechanisms might be for nature exposure to lead to favorable cognitive outcomes for school aged children. There was substantial support for the restorative effects of nature on cognitive functioning. This was ascertained by improved attentional functioning after nature exposure, relative to being amidst built environments, as well as by self-reported accounts about how replenished the students felt after nature exposure. This is consistent with ART and previous studies such as van den Berg et al. (2016) who found that children reported feeling restored after being in nature. While stress reduction, relaxation and well-being were also reported as outcomes in a variety of studies, thus supporting SRT and the biophilia hypothesis respectively, the findings were not always consistently favorable for all outcomes. For example, Greenwood and Gatersleben (2016) found that participants improved their concentration, positive affect and heart rate after a break outdoors in nature (compared with an indoor condition) but their blood pressure did not improve. Interestingly, this study also found that the effects of nature on positive affect were strongest when participants were with a friend as opposed to being alone. Studies like this suggest that there may be a synergistic effect of numerous mediating factors as well as the potential for confounding factors such as social interaction, to contribute to the benefits. In addition, the ability to examine underlying mechanisms depends on the measures selected for the studies and the reliability and validity of these measures to accurately detect change. For example, it may be that certain physiological indices are more sensitive measures of change than others (e.g., heart rate compared with blood pressure) or that subjective experiences may be easier for researchers to measure than physiological outcomes. It is important in the future to design a priori nature studies that can effectively test the relative contributions of theories and mediating factors. This review has identified some likely contributors but a better understanding of the combination of factors that are most conducive to nature benefits will have positive implications for practice and achieving desirable outcomes for cognitive functioning and well-being.

Along these lines, the active or passive role nature plays in exposures may be an important factor to consider when examining cognitive outcomes of nature interventions. The scope of this review does not allow different mechanisms related to types of involvement in nature exposure designs to be identified; however, it would be worth knowing if different forms of engagement with nature lead to different cognitive outcomes. If we use Norwood's (2019) definition of active/passive engagement with nature, most of the included studies in our review used passive rather than active nature exposure as the intervention treatment, that is, nature was used as a background for other activity like walking, active play and sitting quietly while reading. In contrast, in two outdoor education studies (Fagerstam & Blom, 2013; Wells et al., 2015) nature played a central role. In the remaining studies, nature may be argued to have played somewhat of an active role. One study involved a green walk with a series of added short talks to contemplate on nature (Stevenson, Dewhurst, Schilhab, & Bentsen, 2019), and another study (Amicone et al., 2018, study 2) used free play in the garden with the intention of shifting children's attention from an activity of a regular group game. Finally, the green wall study (van den Berg et al., 2017) used living plants designed as a visual focus during the rest period, as a short-term exposure, which would make it an active use of nature. However, the study

also involved a long-term exposure to the green wall in its follow-up, which would make it a passive type of exposure.

The issue of passive/active role nature plays in exposure designs to explain underlying mechanisms in nature-cognition relationship often overlaps with active/passive involvement of participants themselves in how they use the natural environment. The underlying mechanisms may be similar. The nature exposure may facilitate physical activity (e.g., walking or playing in a garden) or simply involve being passive around nature (e.g., looking at nature from a classroom window). It appears that for younger students in primary school, physical activity in nature is common and beneficial. Benefits may be partly due to the physical development and coordination that occurs for young people during this age and their innate drive to play and explore (Fjørtoft, 2004). For high school students, nature exposure effects occurred with as well as without physical involvement—this is a promising finding given that adolescents tend to be at high risk of mental illness and can experience high levels of anxiety (Tiller et al., 2020). A limit to understanding how nature differentially affects children at various ages, is that the focus of the experimental studies has been on high school students. More high-quality research is needed with primary school students, particularly in the early years. Moreover, considering that studies report on various cognitive domains and that they differ substantially in design, study population and nature exposure, the comparison of subgroups is highly restricted. There are also additional differences on how the studies apply statistical adjustments for demographic and socio-economic confounders.

Despite a lack of consistency in findings on long-term nature exposure benefits for cognitive functioning, one should not dismiss positive findings in the area of greening or outdoor education interventions used in short-term school settings. Studies on everyday exposure to greenness for all age groups provide insight into the methods of reducing attentional difficulties and the ways to support academic development (Faber Taylor and Kuo, 2011; Tallis, et al., 2018; Wu et al., 2014). In consideration of education becoming increasingly important for children, particularly as they spend more time in the school environment when they progress through primary, middle and high school levels, more research is focused on school surrounding greenness (Li, et al., 2019; Matsuoka, 2010). Li, et al. (2019) measured greenness as tree cover density and reported a positive association with adolescents' academic performance. More sophisticated measurement of school greenness was applied in Matsuoka's (2010) study to examine how particular nature features around school buildings would be best associated with students' grades. Student performance was positively associated with greater quantities of trees and shrubs, particularly as viewed from their cafeteria. Conversely, large area features like parking lots, campus lawns and athletic fields were negatively related to academic performance.

Hence, greenspace exposure seems to be correlated with children's and adolescents' cognitive functioning in different ways depending on their developmental level. Further investigation of long and short-term effects of well-defined nature exposure over the child's life course has the potential to provide guidance for parents and school leaders on how nature exposure may help students better engage with their learning or improve their overall academic achievement. While research indicates nature exposure benefits across a child's life span, more attention should

be given to identifying specific greenspace features for well-defined and diverse populations. For example, it may be useful to distinguish children with mild symptoms of attention disorders from those with severe symptoms. Findings from Faber et al.'s (2011) study indicate that relatively open grass settings could better alleviate attention symptoms for hyperactive children than settings with trees and grass. School-based short-term interventions may play an important role in self-regulation issues as it is important in everyday school tasks and essential for effective attention functioning (McClelland, et al., 2010). Correspondingly, direct attention—described in ART theory as having limited mental resources and requiring restoration—would equally benefit from nature exposure. Children are being challenged with increasing cognitive demands and nature exposure can be restorative for each age group in different ways. To establish exactly how this occurs, precise descriptions of nature exposure are required. Furthermore, measurements of cognitive functioning should be sensitive enough to detect meaningful differences across the child and adolescents' age span so that age-appropriate nature strategies can be developed.

Strengths, limitations and implications

The high quality of studies included in this review is a strength. This was examined using the EPHPP which assessed six domains (selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts). Ratings were conducted by both authors with near perfect consistency, indicating that 10 of the 12 studies adhered strongly to quality standards and two moderately to quality standards. The main areas of bias occurred mainly in the study design and blinding domains. This is not surprising for nature interventions with ecological validity, where blinding is not really feasible. Another limiting factor concerns the suitability of the comparison group. While it can be argued that greenspace interventions can be compared with alternative conditions that are commonly used in schools, if the comparisons are barren concrete areas like car parks, then the relative benefits of greenspace would not be surprising. Comparing greenspace with other spaces that are aesthetically pleasing, such beautifully designed buildings would make a fairer comparison. Overall, however, the high quality of studies included in this review provide confidence in the findings obtained and the case for investing in nature interventions for improved cognitive health and well-being, particularly for school children.

Our main objective was to establish if the causal effects of nature on cognitive functioning could be demonstrated experimentally in variety of settings involving both short-term and long-term cognitive outcomes. However, this objective presents a challenge to explain precisely how the process occurs. A closer analysis would require refinement of the definition of nature exposure itself. Norwood et. al. (2019) advocate the need to isolate the role of nature exposure in research away from possible confounders. For example, nature exposure in adventure or wilderness therapy is an integral part of such interventions and they use nature in an active way alongside the counselling process itself. For this purpose, they define passive nature exposure

in an attempt to remove it from possible factors like social engagement. Such passive exposure may "take place in a natural environment which itself is not actively integrated or consciously used in an activity" (Norwood et. al., 2019, p.72).

The studies in this review were not designed to examine nature exposure in its pure form that would eliminate the influence of other possible variables, such as being with other people or engaging in various types of physical activity, and they differ in the degree of passive/active use of nature in their exposure settings. The selected studies also focused on real-world settings, including potential confounders such as social interaction and physical activity (see Appendix Table 8 for passive/active dimension of interventions).

Thus, a strength of this review lies in the inclusion of a variety of types of nature exposure in terms of duration and settings to demonstrate causal effect of greenspace on cognitive functioning. However, because of the wide inclusion criteria it was difficult to determine the exact mechanism of impact. Although further analysis of short-term and long-term exposures allowed for identifying factors described in ART theory on attentional processing, there was not enough evidence for explaining mechanisms involved in long-term nature exposures (see Appendix Table 8 for short-term/long-term duration of interventions).

Similarly, this review includes a variety of outcome measures. Some of them are used in a traditional school environment, others, coming from laboratory test settings. This wide inclusion criteria on our outcome measurement is a strength as well as a limitation. Comparing different outcome measures limits generalizing to overall cognitive functioning. However, a wide range of possible cognitive benefits provide an opportunity to further explore the greenspace-cognition relationship. The majority of outcome tests adopted in the included studies are of particular interest. They relate to attentional functioning such as direct attention, selective attention and also mental processing involving tedious activities. These mental functions are in constant demand in school classrooms (Diamond & Taylor, 1996) and require frequent restoration. The studies included in our review show how to restore attention through short-term exposure to nature to maintain students' focus and optimal attentional functioning. We also included studies with traditional outcome measures of academic performance that are mainly designed to examine possible long-term effects of nature exposure. Our findings suggest that employing both types of nature exposures can be beneficial. The short-term nature breaks would maintain basic healthy attentional functioning in the classroom and, at the same time, long-term nature exposure is recommended to provide a supportive environment for other restorative aspects of students' functioning, including social, physical and mental dimensions. Further research is required to identify the exact underlying mechanisms of long-term nature interventions involving holistic approaches to student functioning.

Another limitation is the narrow range of geographical areas of the papers included in this review, with different climates and cultures. Greenness as measured by NDVI most often excludes other colors that are part of nature. For example, autumn color foliage has been perceived as especially restorative by elementary school children when compared to green foliage (Paddle & Gilliland, 2016). The findings indicate that greenspace measures should expand to include orange and perhaps other colors that we can find in high mountainous areas or deserts.

Recommendations for Future Research

A number of design issues warrant attention in experimental studies of nature exposure on cognition. Nature exposure needs to be well described at every stage of the experiment for both short-term and long-term studies. For example, studies that are designed to examine short-time effects of nature on attentional functioning should also be accounting for long-term exposure to the natural environment (like surrounding school, neighborhood, or home greenery) with the same scrutiny as socio-economic status is routinely checked in many studies. Correspondingly, for long-term studies, most often measuring surrounding greenness, the testing environment itself also needs to be described, with special consideration given to any natural green features (e.g., does the testing room have windows with green views, or is there a living plant in the area?).

There is also the issue of lack of consistency between nature exposure experiments of pre-exposure activities. For example, studies in school settings may have specific classes like maths or art before testing. These classes need to be described as they may vary in the extent to which they are cognitively demanding. Likewise, for long-term exposure studies examining for example, school greenness on academic performance, pre-testing conditions like their environment on the way to school, need to be accounted for. For example, some students may need to walk through busy urban streets to get to school for an exam, while some may be walking through a park. Thus, pre-testing conditions need to be accounted for in most experimental designs in order to control possible differences in nature exposure effects.

Conclusion

The positive findings from this review are heartening given the modern-day pressures faced by many young people in westernized society (Blake et al., 2018; Michaelson et al., 2020; Vancampfort et al., 2018) including the pressure to perform well academically (Tiller et al., 2020). The diminishing opportunities for nature exposure, and immersion in the technology saturated lives of young people, heighten the importance of embedding nature in the everyday experiences of young people to enhance mental health (Capaldi et al, 2015; Diaz et al., 2015; Hartig et al., 2014). Hence, exposure to nature during school time is ideal. The findings that short-term active and passive nature interventions were effective for promoting cognitive functioning makes the integration of nature into school life feasible. It is also worthwhile given that nature exposure facilities cognitive qualities such as attention, memory and knowledge acquisition that are conducive to learning (Mason et al., 2021). Urban planners and educators need to consolidate efforts to create a range of short and long duration nature interventions including school yard greening, internal greening, classroom views of nature and curriculum focused on biology, horticulture, sustainability and biodiversity. Preliminary findings suggest this would create a physiologically calming and restorative environment conducive to improved attention and knowledge acquisition—both of which are essential for learning. Support for school-based exposure to nature is growing and this systematic review focusing on high quality experimental studies, has contributed to a tipping point of evidence favoring the dissemination of nature interventions for enhanced cognitive functioning with children and adolescents.

Appendix

Table 7 Attention performance tests by cognitive domains

Attention performance measures; Author (substudy); (Outcome)	Domain of cognition	Test Description
Digit Span Forward Digit Span Backward; Amicone et al. (1); (+) Li and Sullivan); (+)	Working memory—performance relies on the ability to hold and manipulate to-be remembered information in the short-term to enable goal directed behaviour	A series of digits given in longer lists (from 2 to 6 digits) if done successfully until two subsequent fails. The task in the Digit Span Forward – to recall the digits in the same order presented. The task in the Digit Span Backward – to recall the digits in the reverse order
The Bells Test; Amicone et al. (1); (+) Amicone et al. (2); (+)	Selective attention, sustained attention—the need to direct attention towards a target while simultaneously ignoring distractors	The test—four different sheets with small black drawings of different symbols (house, tree, bird, bell, etc.). The task – to mark all the 35 bells embedded within 280 different distracting symbols
CAST; (fish flanker task); Johnson et al.; Orienting (+) Alerting (+) Others (-)	Selective attention, orienting, alerting – the test requires directed attention on mainly visual stimuli and also auditory stimuli	Computer test—the target fish is presented alone or surrounded by a school of fish (flankers) that are facing in either the same or opposite direction of the target fish. The variables manipulated in the task are: target fish direction (left vs. right facing), location (left vs. right); flankers (none, congruent incongruent); auditory and visual cues. The task – indicate the correct direction of the target fish
ANT; (fish flanker task); Stevenson et al.; (+)	Selective attention—(1) executive attention score (EXE) as an index of directed attention ability; (2) standard error of RT on all correct trials (SERT); 3) mean RT on all correct trials (mRT); (4) total accuracy (ACC)	Computer test – The target fish is presented centrally facing left or right and is flanked by other fish pointing in congruent or incongruent directions. The variables manipulated in the task: spatial cue (cue vs. no cue, cue vs. neutral cue). The task – indicate the correct direction of the centrally located target fish

Table 7 (continued)

Attention performance measures; Author (substudy); (Outcome)	Domain of cognition	Test Description
NCPCT (number of reversals); Greenwood and Gatersleben; (+)	Selective attention, concentration on visual stimuli. The test requires directed attention to hold one perspective of the cube for as long as possible	The test – a drawing of 3D cube image which may be perceived from alternative perspectives. The task – to focus on one perspective for as long as one could and tap on the table every time the pattern shifts
Sky Search Task; van den Berg et al.; (+) van Dijk-Wesselius et al.; (trend only)	Sustained/selective attention – visual scanning, the test also requires the ability to attend to relevant visual stimuli while ignoring irrelevant stimuli	The test – an A4 paper with rows of pictures of identical or different spacecraft pairs. The task – to underline identical pairs in 40 s. Different versions of the test with different spacecrafts' configurations are used at each time of measurement
D2-R Test; Wallner et al.; (+) Mygind et al.; (-)	Sustained/selective attention, visual scanning speed, processing speed, concentration, the test also requires the ability to attend to relevant visual stimuli while ignoring irrelevant stimuli	The test – 14 rows of "d" and "p" letters with one, two or three marks. The task—to identify and cross out the letter "d" with two apostrophes in each row and and to move on to the next row after every 20 s periods
Digit Letter Substitution Test; van den Berg et al.; (-) van Dijk-Wesselius et al.; (+)	Information processing speed	The test – randomly ordered digits (1–9) with a key that assigns a letter (L, H, Y, N, R, E, D, T, S) to each number. The task—to convert randomly ordered digits to letters according to the key within 90 s. Different versions of the test with different keys
Go/No-Go test; Amicone et al. (1); (+)	Impulse control—the test requires one to process auditory stimuli to respond with action or inaction to demonstrate the capacity to inhibit a dominant response	The test – a sheet with 20 items, each item composed a drawing of a "path" made up of 14 squares. The task – to respond to the "go" and "no-go" sounds by either dotting the square or not making the move on the path

CAST—Combined Attention Systems Test; *ANT*—The Attention Network Task; *NCPCT*—Necker Cube Pattern Control Task

Table 8 Intervention duration by active/passive dimension

Author, Year, (sub-study)	Cognitive performance measures; (Outcome)	Other measures (Outcome)	Passive/Active
Nature exposure time from 20–30 min for immediate post intervention designs			
Amicone et al. (2018), (1)	The Bells Test; (+) Digit Span Forward; (+) Digit Span Backward; (+) Go/No-Go test; (-)	PRS (+)	Passive (30 min active play)
Amicone et al. (2018), (2)	The Bells Test; (+)	PRS (+)	Passive and a possibility of Active (30 min free play)
Greenwood and Gatersleben (2016)	NCPCT (number of reversals); (+)	Heart Rate; (+) Blood Pressure; (-) ZIPPERS; Positive affect (+)	Passive (20 min alone vs. with a friend vs. phone game)
Johnson et al. (2019)	CAST; Orienting (+) Alerting (+) Others (-)	CNS as control	Passive (30 min walk)
Stevenson et al. (2019)	ANT (fish flanker task); (+)	PRS-CII as control Mobile eye tracking (+)	Passive with a possibility of Active (30 min contemplative walk)
Nature exposure time of 60 min for post intervention designs (+20 min)			
Wallner et al. (2018)	D2-R Test; (+)	Nitsch scale; (+)	Passive (60 min walk + 20 min drive)
Nature exposure time from a few to 60 min for during intervention designs (+activity time)			
Li and Sullivan (2016)	Digit Span Forward & Digit Span Backward (+)	VAS-self-reported attentional functioning; (+) during 30 min class Physiological stress; (+)	Passive (seated and resting for 10 min activity)
Mygind et al. (2018)	D2-R Test; (-)	PHASIC; (+)	Passive (reading quietly plus 20 min testing time)

Table 8 (continued)

Author, Year, (sub-study)	Cognitive performance measures; (Outcome)	Other measures (Outcome)	Passive/Active
Long-term nature exposure from 2 months to 2 years			
Fägerstam and Blom (2013)	An essay-type question on biology course content	Semi-structured interviews for cognitive and emotional dimensions (+)	Active (outdoor lessons over 8 weeks, measured at 5 and 6 months)
van den Berg et al. (2017)	Digit Letter Substitution Substitution Test; (-) Sky Search Task; (+)	Self-reported ability to concentrate; (-) Self- reported emotional state; (-)	Active (few minutes of viewing the green wall), Passive (2 and 4 months of using the classroom with the green wall)
van Dijk- Wesselius et al. (2018)	Digit Letter Substitution Test; (+) Sky Search Task; (trend only, p = .08)	Appreciation of the Schoolyard; (+) PRCS; (-), (+) PQLS; (-)	Passive (recess time in school green area for 1 and 2 years)
Wells et al. (2015)	Science knowledge measured (7-item questionnaire on nutrition and plants	GIF as control	Active (19 garden lessons, measured at 1 and 2 years)

PRS—Perceived Restorativeness Scale; *NCPCT*—Necker Cube Pattern Control Task; *ZIPPERS*—the ZIPPERS emotional restoration; *CAST*—Combined Attention Systems Test; *CNS*—Connectedness to Nature Scale; *ANT*—The Attention Network Task; *ZIPPERS*—the ZIPPERS emotional restoration; *PHASIC*—the difference between tonic and event vagal tone; *PRCS*- Perceived Restorative Components Scale; *PQLS*-Pediatric Quality of Life Scale; *GIF*- Garden Intervention Fidelity

(+) significant positive result, (-) not significant result

Acknowledgements Dianne Vella-Brodrick would like to thank the Higgins family for supporting her role as Gerry Higgins Chair in Positive Psychology. This role has enabled the development of a new research program on Nature and Wellbeing which has commenced with this review paper.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions.

References

*Amicone, G., Petruccelli, I., De Dominicis, S., Gherardini, A., Costantino, V., Perucchini, P., & Bonaiuto, M. (2018). Green Breaks: The restorative effect of the school environment's green areas on children's cognitive performance. *Frontiers in Psychology*, *9*(OCT). https://doi.org/10.3389/fpsyg.2018.01579

Astell-Burt, T., & Feng, X. (2020). Greener neighbourhoods, better memory? A Longitudinal Study. *Health and Place*, *65*(July), 102393. https://doi.org/10.1016/j.healthplace.2020.102393

Barrable, A., & Booth, D. (2020). Increasing Nature Connection in Children: A Mini Review of Interventions. *Frontiers in Psychology*, *11*(March). https://doi.org/10.3389/fpsyg.2020.00492

Becker, C., Lauterbach, G., Spengler, S., Dettweiler, U., & Mess, F. (2017). Effects of regular classes in outdoor education settings: A systematic review on students' learning, social and health dimensions. *International Journal of Environmental Research and Public Health, 14*(5), 1–20. https://doi.org/10.3390/ijerph14050485

Blake, M. J., Trinder, J. A., & Allen, N. B. (2018). Mechanisms underlying the association between insomnia, anxiety, and depression in adolescence: Implications for behavioral sleep interventions. *Clinical Psychology Review, 63*(January), 25–40. https://doi.org/10.1016/j.cpr.2018.05.006

Braun, T., & Dierkes, P. (2017). Connecting students to nature–how intensity of nature experience and student age influence the success of outdoor education programs. *Environmental Education Research, 23*(7), 937–949. https://doi.org/10.1080/13504622.2016.1214866

Capaldi, C., Passmore, H.-A., Nisbet, E., Zelenski, J., & Dopko, R. (2015). Flourishing in nature: A review of the benefits of connecting with nature and its application as a wellbeing intervention. *International Journal of Wellbeing, 5*(4), 1–16. https://doi.org/10.5502/ijw.v5i4.449

Dadvand, P., Nieuwenhuijsen, M. J., Esnaola, M., Forns, J., Basagaña, X., Alvarez-Pedrerol, M., & Sunyer, J. (2015). Green spaces and cognitive development in primary school children. *Proceedings of the National Academy of Sciences of the United States of America, 112*(26), 7937–7942. https://doi.org/10.1073/pnas.1503402112

Dadvand, P., Pujol, J., Maciá, D., Martínez-Vilavella, G., Blanco-Hinojo, L., Mortamais, M., & Sunyer, J. (2018). The association between lifelong greenspace exposure and 3-dimensional brain magnetic resonance imaging in Barcelona schoolchildren. *Environmental Health Perspectives, 126*(2), 1–8. https://doi.org/10.1289/EHP1876

Deeks, J. J., Dinnes, J., D'Amico, R., Sowden, A. J., Sakarovitch, C., Song, F., … Altman, D. G. (2003). Evaluating non-randomised intervention studies. *Health Technology Assessment (Winchester, England)*, *7*(27), iii – x, 1–173. https://doi.org/10.3310/hta7270

Dettweiler, U., Becker, C., Auestad, B. H., Simon, P., & Kirsch, P. (2017). Stress in school. Some empirical hints on the circadian cortisol rhythm of children in outdoor and indoor classes. *International Journal of Environmental Research and Public Health*, *14*(5). https://doi.org/10.3390/ijerph14050475

Diamond, A., & Taylor, C. (1996). Development of an aspect of executive control: Development of the abilities to remember what I said and to "do as I say, not as I do." *Developmental Psychobiology,*

29(4), 315–334. https://doi.org/10.1002/(SICI)1098-2302(199605)29:4%3c315::AID-DEV2%3e3.0.CO;2-T

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., & Zlatanova, D. (2015). The IPBES Conceptual Framework — connecting nature and people. *Current Opinion in Environmental Sustainability, 14*, 1–16. https://doi.org/10.1016/j.cosust.2014.11.002

Effective Public Health Practice Project. (2010). *Quality Assessment Tool for Quantitative Studies*, (1998), 1–4. Retrieved from https://merst.ca/wp-content/uploads/2018/02/quality-assessment-tool_2010.pdf

Faber Taylor, A., & Kuo, F. E. M. (2011). Could exposure to everyday green spaces help treat adhd? Evidence from children's play settings. *Applied Psychology: Health and Well-Being, 3*(3), 281–303. https://doi.org/10.1111/j.1758-0854.2011.01052.x

*Fägerstam, E., & Blom, J. (2013). Learning biology and mathematics outdoors: Effects and attitudes in a Swedish high school context. *Journal of Adventure Education and Outdoor Learning, 13*(1), 56–75. https://doi.org/10.1080/14729679.2011.647432.

Fjørtoft, I. (2004). Landscape as Playscape: The Effects of Natural Environments on Children's Play and Motor Development. *Children, Youth and Environment, 14*(2), 21–44. https://doi.org/10.7721/chiloutenvi.14.2.0021

Flouri, E., Papachristou, E., & Midouhas, E. (2019). The role of neighbourhood greenspace in children's spatial working memory. *British Journal of Educational Psychology, 89*(2), 359–373. https://doi.org/10.1111/bjep.12243

*Greenwood, A., & Gatersleben, B. (2016). Let's go outside! Environmental restoration amongst adolescents and the impact of friends and phones. *Journal of Environmental Psychology, 48*, 131–139. https://doi.org/10.1016/j.jenvp.2016.09.007

Hartig, T., Mitchell, R., de Vries, S., & Frumkin, H. (2014). Nature and Health. *Annual Review of Public Health, 35*(1), 207–228. https://doi.org/10.1146/annurev-publhealth-032013-182443

Jackson, N., & Waters, E. (2005). Criteria for the systematic review of health promotion and public health interventions. *Health Promotion International, 20*(4), 367–374. https://doi.org/10.1093/heapro/dai022

*Johnson, S. A., Snow, S., Lawrence, M. A., & Rainham, D. G. C. (2019). Quasi-Randomized Trial of Contact With Nature and Effects on Attention in Children. *Frontiers in Psychology, 10*,. https://doi.org/10.3389/fpsyg.2019.02652

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology, 15*(3), 169–182. https://doi.org/10.1016/0272-4944(95)90001-2

Kuo, M., Barnes, M., & Jordan, C. (2019). Do experiences with nature promote learning? Converging evidence of a cause-and-effect relationship. *Frontiers in Psychology, 10*(FEB), 1–9. https://doi.org/10.3389/fpsyg.2019.00305

Lee, M., Kim, S., & Ha, M. (2019). Community greenness and neurobehavioral health in children and adolescents. *Science of the Total Environment, 672*, 381–388. https://doi.org/10.1016/j.scitotenv.2019.03.454

Li, D., Chiang, Y. C., Sang, H., & Sullivan, W. C. (2019). Beyond the school grounds: Links between density of tree cover in school surroundings and high school academic performance. *Urban Forestry and Urban Greening, 38*(November 2017), 42–53. https://doi.org/10.1016/j.ufug.2018.11.001

*Li, D., & Sullivan, W. C. (2016). Impact of views to school landscapes on recovery from stress and mental fatigue. *Landscape and Urban Planning, 148*, 149–158. https://doi.org/10.1016/j.landurbplan.2015.12.015

Liao, J., Zhang, B., Xia, W., Cao, Z., Zhang, Y., Liang, S., … Li, Y. (2019). Residential exposure to green space and early childhood neurodevelopment. *Environment International*, *128*(October 2018), 70–76. https://doi.org/10.1016/j.envint.2019.03.070

Markevych, I., Feng, X., Astell-Burt, T., Standl, M., Sugiri, D., Schikowski, T., & Heinrich, J. (2019). Residential and school greenspace and academic performance: Evidence from the GINIplus and LISA longitudinal studies of German adolescents. *Environmental Pollution, 245*, 71–76. https://doi.org/10.1016/j.envpol.2018.10.053

Mason, L., Ronconi, A., Scrimin, S., & Pazzaglia, F. (2021). Short-term exposure to nature and benefits for students' cognitive performance: A review. *Educational Psychology Review*. https://doi.org/10.1007/s10648-021-09631-8

Matsuoka, R. H. (2010). Student performance and high school landscapes: Examining the links. *Landscape and Urban Planning, 97*(4), 273–282. https://doi.org/10.1016/j.landurbplan.2010.06.011

Mayer, F. S., & Frantz, C. M. P. (2004). The connectedness to nature scale: A measure of individuals' feeling in community with nature. *Journal of Environmental Psychology, 24*(4), 503–515. https://doi.org/10.1016/j.jenvp.2004.10.001

McClelland, M. M., Ponitz, C. C., Messersmith, E. E., & Tominey, S. (2010). *Self-regulation: Integration of cognition and emotion*. In W. F. Overton & R. M. Lerner (Eds.), The handbook of life-span development, Vol. 1. Cognition, biology, and methods (pp. 509–553). John Wiley & Sons, Inc.. https://doi.org/10.1002/9780470880166.hlsd001015

Michaelson, V., King, N., Janssen, I., Lawal, S., & Pickett, W. (2020). Electronic screen technology use and connection to nature in Canadian adolescents: a mixed methods study. *Canadian Journal of Public Health*, *111*. https://doi.org/10.17269/s41997-019-00289-y

Mygind, L., Kjeldsted, E., Hartmeyer, R., Mygind, E., Bølling, M., & Bentsen, P. (2019). Mental, physical and social health benefits of immersive nature-experience for children and adolescents: A systematic review and quality assessment of the evidence. *Health and Place*, *58*(October 2018), 102136. https://doi.org/10.1016/j.healthplace.2019.05.014

*Mygind, L., Stevenson, M. P., Liebst, L. S., Konvalinka, I., & Bentsen, P. (2018). Stress response and cognitive performance modulation in classroom versus natural environments: A quasi-experimental pilot study with children. *International Journal of Environmental Research and Public Health*, *15*(6). https://doi.org/10.3390/ijerph15061098

Nitsch, J. R. (1976). The self condition scale. Die Eigenzustandsskala (EZ-Skala)—Ein Verfahren zur hierarchisch-mehrdimensionalen Befindlichkeitsskalierung. *Beanspruchung im Sport; Nitsch, J., Udris, I., Eds.; Limpert: Bad Homburg, Germany*, 81–102.

Norwood, M., Fullagar, S., & Kendall, E. (2019). A narrative and systematic review of the behavioural, cognitive and emotional effects of passive nature exposure on young people: Evidence for prescribing change. *Landscape and Urban Planning, 189*, 71–79. https://doi.org/10.1016/j.landurbplan.2019.04.007

Paddle, E., & Gilliland, J. (2016). Orange is the new green: Exploring the restorative capacity of seasonal foliage in schoolyard trees. *International Journal of Environmental Research and Public Health*, *13*(5). ://doi.org/https://doi.org/10.3390/ijerph13050497

Reuben, A., Arseneault, L., Belsky, D. W., Caspi, A., Fisher, H. L., Houts, R. M., & Odgers, C. (2019). Residential neighborhood greenery and children's cognitive development. *Social Science and Medicine, 230*(April), 271–279. https://doi.org/10.1016/j.socscimed.2019.04.029

Roberts, A., Hinds, J., & Camic, P. M. (2020). Nature activities and wellbeing in children and young people: A systematic literature review. *Journal of Adventure Education and Outdoor Learning, 20*(4), 298–318. https://doi.org/10.1080/14729679.2019.1660195

*Stevenson, M. P., Dewhurst, R., Schilhab, T., & Bentsen, P. (2019). Cognitive restoration in children following exposure to nature: Evidence from the attention network task and mobile eye tracking. *Frontiers in Psychology*, *10*(FEB), 1–10. https://doi.org/10.3389/fpsyg.2019.00042

Stevenson, M. P., Schilhab, T., & Bentsen, P. (2018). Attention Restoration Theory II: A systematic review to clarify attention processes affected by exposure to natural environments. *Journal of Toxicology and Environmental Health - Part b: Critical Reviews, 21*(4), 227–268. https://doi.org/10.1080/10937404.2018.1505571

Thomas, B. H., Ciliska, D., Dobbins, M., & Micucci, S. (2004). A Process for Systematically Reviewing the Literature : Providing the Research Evidence. *Worldwide Views on Evidence-Based Nursing*, *1*(3), 176–184. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17163895

Tiller, E., Fildes, J., Hall, S., Hicking, V., Greendland, N., Liyanarachchi, D., & Di Nicola, K. (2020). *Youth Survey Report 2020*. Mission Australia.

Ulrich, R. S. (1983). Behavior and the Natural Environment. *In Behavior and the Natural Environment*. https://doi.org/10.1007/978-1-4613-3539-9

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology, 11*(3), 201–230. https://doi.org/10.1016/S0272-4944(05)80184-7

*van den Berg, A. E., Wesselius, J. E., Maas, J., & Tanja-Dijkstra, K. (2017). Green Walls for a Restorative Classroom Environment: A Controlled Evaluation Study. *Environment and Behavior, 49*(7), 791–813. https://doi.org/10.1177/0013916516667976

van den Berg, A., Joye, Y., & Koole, S. (2016). Why Viewing Nature is More Fascinating and Restorative Than Viewing Buildings: A Closer Look at Perceived Complexity. *Urban Forestry & Urban Greening, 20*, 397–401. https://doi.org/10.1016/j.ufug.2016.10.011

*van Dijk-Wesselius, J. E., Maas, J., Hovinga, D., van Vugt, M., & van den Berg, A. E. (2018). The impact of greening schoolyards on the appreciation, and physical, cognitive and social-emotional well-being of schoolchildren: A prospective intervention study. *Landscape and Urban Planning, 180*, 15–26. https://doi.org/10.1016/j.landurbplan.2018.08.003

Vanaken, G. J., & Danckaerts, M. (2018). Impact of green space exposure on children's and adolescents' mental health: A systematic review. *International Journal of Environmental Research and Public Health*, *15*(12). https://doi.org/10.3390/ijerph15122668

Vancampfort, D., Stubbs, B., Firth, J., Van Damme, T., & Koyanagi, A. (2018). Sedentary behavior and depressive symptoms among 67,077 adolescents aged 12–15 years from 30 low- and middle-income countries. *International Journal of Behavioral Nutrition and Physical Activity, 15*(1), 73. https://doi.org/10.1186/s12966-018-0708-y

*Wallner, P., Kundi, M., Arnberger, A., Eder, R., Allex, B., Weitensfelder, L., & Hutter, H. P. (2018). Reloading pupils' batteries: Impact of green spaces on cognition and wellbeing. *International Journal of Environmental Research and Public Health*, *15*(6). https://doi.org/10.3390/ijerph15061205

Weeland, J., Moens, M. A., Beute, F., Assink, M., Staaks, J. P. C., & Overbeek, G. (2019). A dose of nature: Two three-level meta-analyses of the beneficial effects of exposure to nature on Children's self-regulation. *Journal of Environmental Psychology, 65*(August), 101326. https://doi.org/10.1016/j.jenvp.2019.101326

*Wells, N. M., Myers, B. M., Todd, L. E., Barale, K., Gaolach, B., Ferenz, G., & Falk, E. (2015). The Effects of School Gardens on Children's Science Knowledge: A randomized controlled trial of low-income elementary schools. *International Journal of Science Education, 37*(17), 2858–2878. https://doi.org/10.1080/09500693.2015.1112048

Wilson, E. O. (1984). *Biophilia*. Harvard University Press.

Zuckerman, M. (1977). Development of a situation-specific trait-state test for the prediction and measurement of affective responses. *Journal of Consulting and Clinical Psychology, 45*(4), 513–523. https://doi.org/10.1037/0022-006X.45.4.513

Authors and Affiliations

Dianne A. Vella-Brodrick[1] · Krystyna Gilowska[1]

Krystyna Gilowska
Krystyna.gilowska@unimelb.edu.au

[1] Melbourne Graduate School of Education, Centre for Wellbeing Science, University of Melbourne, Level 2, 100 Leicester St, Victoria 3010, Australia