

Measuring Green Space Effects on Attention and Stress in Children and Youth: A Scoping Review

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Abstract

This scoping review compiles 42 published studies measuring children's attention and/or stress responses to green space settings. Attention and stress outcomes include objective (e.g., physiological) and subjective (rating scale) traditions. Attention studies had two distinct subjective measurement traditions, one measuring ADHD symptoms, the other measuring attention restoration theory constructs. Correlational studies were more likely to use subjective scales for outcomes whereas experimental studies more frequently used objective measures or a mix of objective and subjective measures. Care should be taken when interpreting and extending this literature as the comparability of outcome variables across studies is unclear.

Keywords: children, green space, nature, tree canopy, attention restoration, stress reduction

Introduction

Evidence shows that natural environments can beneficially impact human health (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Hartig, Mitchell, De Vries, & Frumkin, 2014; Ideno et al., 2017; Kuo, 2015; Nesbitt, Hotte, Baron, Cowan, & Shepard, 2017). Although most research has been conducted on adult populations, a growing literature identifies benefits for children and adolescents (Chawla, Keena, Pevec, & Stanley, 2014; Chawla, 2015; Collado & Staats, 2016; Gray et al., 2015; McCormick, 2017). Several reviews exist on the effects of nature on children's mental health and well-being, physical health and activity, academic outcomes, and executive functioning (Alderton, Villanueva, O'Connor, Boulange, & Badland, 2019; Browning & Rigolon, 2019; Chawla, 2015; McCormick, 2017; Gray et al., 2015; Kabisch, van den Bosch, & Laforzezza, 2017; Lambert et al., 2018; Moens et al., 2019; Vanaken & Danckaerts, 2018; Vanos, 2015). Data generally supports that exposure to natural environments is associated with improvements in child outcomes, though effects can be quite small (Moens et al., 2019). Nature as a construct also varies widely across studies with a primary split between "green" (e.g., treed areas) and "blue" (e.g., open-sky areas) spaces (Amoly et al., 2014; Gascon et al., 2015). This study focuses on green spaces.

Attention and stress are two of the most commonly studied health outcomes in the green space literature (Bowler et al., 2010; Hartig et al., 2014; Kuo, 2015). Both are multi-faceted constructs with frequently studied dynamic bi-directional relationships (Eldar, Ricon, & Bar-Haim, 2008; Ferrier, Bassett, & Denham, 2014; Gable & Harmon-Jones, 2010; Graziano, Calkins & Keane, 2011; Monroe, 2008; Moran, 2016; Yiend, 2010). Attention is a notably thorny construct with disparate theories and measures proposed, not to mention complex intersections with other cognitive processes, such as working memory (Awh, Vogel, & Oh, 2006; Cowan, 2001; Diamond, 2013; Cuevas & Bell, 2014; Gaertner, Spinrad, & Eisenberg, 2008; Garon, Bryson, & Smith, 2008; Joyce, Friedman, Wolfe, & Bell, 2018; Woodman & Luck, 1999). Similarly, stress has a dynamic, interactive relationship with anxiety, cognitive functioning, and attention (Eldar et al., 2008; Morales, Fu, & Pérez-Edgar, 2016; Tu et al., 2007; White et al., 2017).

The dominant explanatory theories used to frame research on the effects of green space on measures of attention and stress include Attention Restoration Theory (ART; Kaplan & Kaplan, 1989; Kaplan, 1995) and Stress Reduction Theory (SRT; Ulrich, 1993). ART maintains that exposure to nature decreases mental fatigue and increases attentional capacity (Kaplan, 1995; Kaplan & Kaplan, 1989; Kaplan & Berman, 2010). SRT posits that nature exposure decreases anxiety and stress with downstream effects on human health and well-being (Hartig et al., 2014; Kuo, 2015). These are complementary theories with sizable literatures that are primarily adult-focused and cross-sectional, though experimental studies are increasing (Bowler et al., 2010; Hartig et al., 2014; Kuo, 2015). Notably, ART has been criticized in recent years due to operational imprecision and weak study effects (Joye & Dewitte, 2018; Moens et al., 2019; Neilson, Craig, Travis & Klein, 2019; Ohly et al., 2016). Although SRT has not been similarly scrutinized, there are many operational and interpretive challenges related to measuring stress (Endler & Parker, 1990; Monroe, 2008).

Measuring Attention and Stress

Currently, no structured reviews exist focusing on what measures of green space, attention, and stress are used in published research on children. Measurement of theoretical constructs in relation to health outcomes is challenging, particularly when constructs are measured across children's dynamic developmental stages (Cano & Hobart, 2011; Murray, Obsuth, Eisner, & Ribeaud, 2019). A measurement-focused review will clarify for researchers which attention and stress measures are commonly used across the literature and facilitate discussions on where nature fits within social-ecological frameworks (Bronfenbrenner, 2005). Further, a measurement review will help the field interpret research findings and clarify when studies may be using the same terms to discuss different constructs or different terms to discuss the same constructs (Block, 2000; Kelley, 1927; Reschly & Christenson, 2012; Thorndike, 1904).

To facilitate this conversation, we will discuss published findings using the umbrella terms of *objective* and *subjective* measurement. Objective measures include physiological measures (e.g., cortisol for stress), behavioral measures (e.g., counts of particular behaviors), or perceptual/cognitive tasks (e.g., in vivo attention tasks). Subjective measures are most often Likert-based rating forms (Bagot, Allen, & Toukhsati, 2015; Kuo, Browning, & Penner, 2017; Torquati, Schutte, & Kiat, 2017; van Aart et al., 2018; Wells, 2000).

Researchers of children in green space should take note of the differential support for relationships between objective and subjective attention and stress measures. On the positive side, there is a well-established evidence base indicating objective cortisol responses and heart rate metrics correlate with subjective measures of psychological stress (Aguilar et al., 2014; Burke, Davis, Otte, & Mohr, 2005; Michels et al., 2013; Pagliaccio et al., 2014). The relationship between objective and subjective measures of attentional processes is less clear. For example, a number of studies find that subjective attention scales do not correlate strongly with objective attention tasks (e.g., working memory), suggesting they measure dissimilar constructs (Bodnar, Prahme, Cutting, Denckla, & Mahone, 2007; Limbers, Young, Jernigan, Bryant, & Stephen, 2017; MacAllister et al., 2012; Snyder, Miyake, & Hankin, 2015; Toplak, West, & Stanovich, 2013). The disjoint between purportedly similar subjective and objective metrics is notable as a number of subjective scales explicitly measuring ART constructs have been developed (Bagot, 2004; Kaplan & Berman, 2010). These scales measure the subjective feeling of an individual being physically or psychologically "away," environmental "compatibility," experience of "fascination," and feelings of "connectedness." Such scales are quite different from objective attention measures (Ohly et al., 2016). Furthermore, the relationship between ART-focused scales and other subjective attention scales is not an area of active investigation and the degree to which they measure overlapping constructs is unknown. As such, reviewing the measures used to date will help researchers critique the evidence base, engage in clarifying constructs, and map out future research directions.

Measuring Green Space

Measuring green space is also complex (Taylor & Hochuli, 2017). Published studies in the child literature report measuring green space around houses or schools with access via windows, experimentally controlling time outdoors, or counting the number and types of vegetation around dwelling areas (Li & Sullivan, 2016; Wells, 2000; Soderstrom et al., 2013; Faber Taylor & Kuo, 2009; Torquati et al., 2017). Some researchers develop their own instruments, while others use validated environmental green space measures (Corraliza, Collado, & Bethelmy, 2012; Kuo & Faber Taylor, 2004; Dzhamabov, Hartig, Markevych, Tilov, & Dimitrova, 2018; Wells, 2000). Recent research has begun incorporating satellite-based measures (e.g., the normalized difference vegetation index [NDVI]) to quantify spaces (Dzhamabov et al., 2018; Larson et al., 2011; 2018). Further, while some studies provide granular environmental details, others simply contrast “green” and “non-green” spaces broadly (Mygind, Stevenson, Liebst, Konvalinka, & Bentsen, 2018). A review outlining operational definitions and measures of green space will help researchers better navigate, critique, and extend the existing literature.

Limitations of Current Literature

Despite numerous reviews of the relationship between nature, attention, and stress in adults, there have been few attempts to catalogue the growing body of research on the effects of green spaces in young people. In particular, despite interest (Müller & Liben, 2017), there are currently no systematic attempts to determine the degree to which attention and stress measures, commonly interpreted in relation to ART and SRT, are represented in the child development literature. Reviewing existing studies will help researchers better assess the different ways green space, stress and attention are measured in the literature, and plan future studies from a developmental science perspective. Thus, we propose to conduct a scoping review answering the following questions:

1. What are the different ways that attention and stress are measured in the children’s green space literature?
2. What are the different ways that green space is measured in this literature?

Methods

Scoping Review

Considering the measurement focus of this review, the authors conducted a scoping review guided by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement (Moher, Liberati, Tetzlaff, & Altman, 2009; Munn et al., 2018). Scoping reviews are used to delineate the scope of a subject, identify available evidence, clarify concepts/definitions, organize and examine the current state of research approaches, and identify knowledge gaps (Munn et al., 2018). The authors considered conducting a systematic review of the topic, but considering this technique’s frequent role in informing policy, and the inchoate state of the literature, the authors decided a scoping review was more appropriate.

Literature Search and Title, Abstract, and Article Screening

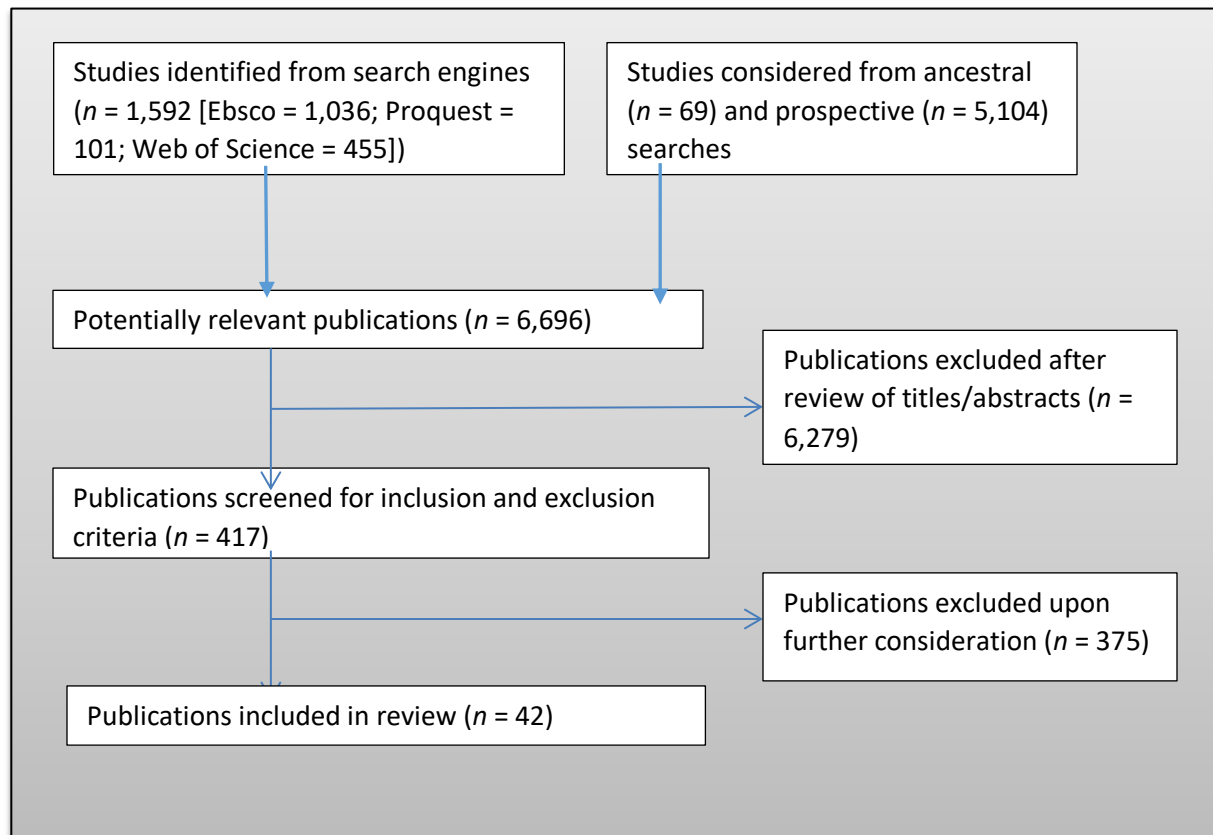
The authors used PsycINFO, Proquest, and Web of Science to identify articles related to green space, ART and SRT. We used search terms including the following: "forest" OR "tree*" OR "shinrin-yoku" (Japanese forest bathing) AND "attention restor*" OR "stress reduct*." We also conducted ancestral and citation searches from highly relevant studies. Article identification included three waves: (1) initial search, (2) ancestral searches and (3) prospective searches. During the initial search (extracted 5/21/2018), the first author reviewed the titles and abstracts of the output from the initial search terms. The core list that this generated was provided to a research assistant, who downloaded the articles from online, university, or inter-library loan resources, and put them into a shared Dropbox ® account.

The first author conducted a preliminary review of the articles collected in the initial search. Studies that were on adults, in a non-English language, single-case designs, qualitative, only measured non-attention/stress outcomes, not published in peer reviewed journals, or whose "natural" settings were indoors were not selected for inclusion in this study.¹ Articles accepted for inclusion included peer-reviewed studies that were on children and youth aged 18 years or younger, written in English, empirical with a minimum of 10 participants per study, clearly measured attention and stress metrics as outcomes, and were conducted in relation to outdoor green spaces.

Following identification of the first round of articles from the initial literature search, all accepted articles were subjected to an ancestral search wherein potential articles were identified from article bibliographies and subjected to the same inclusion/exclusion criteria discussed above. Following initial and ancestral searches, the authors conducted GoogleScholar searches (on 9/25/2018) to review all the articles citing the identified relevant studies, and followed the procedures described for initial search. Figure 1 describes the overall screening and article identification process.

¹ Studies with age ranges including adults were accepted if the mean of the population was under the age of 18 years old.

Figure 1. Flow diagram displaying decision-making criteria across the literature search and selection



Coding

The 42 articles that met the selection criteria were read in order to abstract the following information: Total N, count of participants by gender, green space measures, attention measures, stress measures, other measures, study design, key findings, study population, and co-variables. Green space measures included: (a) place-based metrics wherein nature was measured broadly as “green” spaces, typically contrasted with “non-green” spaces, but without specific metrics attempting to measure amount or degree of green space; (b) satellite-based technology metrics of local topology; (c) researcher-designed instruments (RDIs) measuring green space; and (d) validated scales supported by previously published research. Attention-Relevant Measures (ARM) included objective and subjective measures of attention. Stress-Relevant Measures (SRM) included objective and subjective stress measures. Non SRM/ARM measures were broken into objective and subjective categories, and organized into health-oriented (physical and mental), education-oriented, and environmental-oriented measures. Study design categories included correlational, cross-sectional, quasi-experimental, and experimental designs. Statistical approaches were also coded. When adjusted and unadjusted models were included in studies, we prioritized tabling adjusted analyses rather than findings wherein statistical relations between green space and

outcomes were better accounted for by a confounding variable in multivariate analyses. Reported covariates were also abstracted.

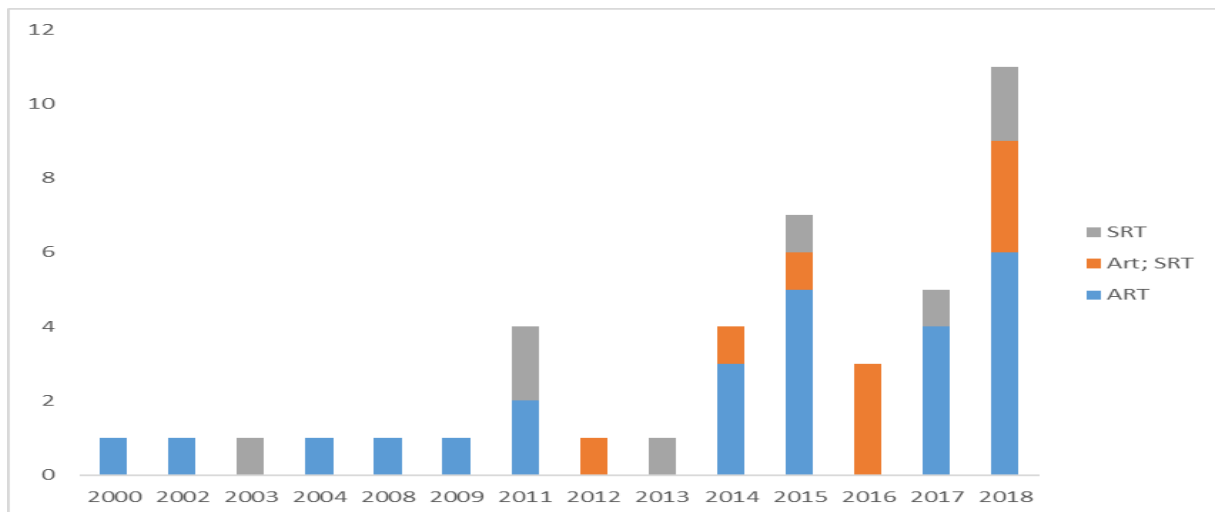
Prior to final reporting, one author independently abstracted 10 (23.8%) of the identified studies to ensure abstraction of key metrics were sound. Analyses indicated near perfect agreement for the number of participants ($r = 0.99$), nature measures ($k = 0.92[0.76-1.0]$), attention measures (objective $k = 0.81[0.50-1.0]$; subjective $k = 1.0$), stress measures (objective $k = 1.0$; subjective $k = 0.81[0.50-1.0]$) and study design ($k = 0.80[0.44-1.0]$).

Results

Overview

The 42 studies identified included 24 ARM studies, eight SRM studies, and 10 with both ARM and SRM. Historically, the child green space literature focused mainly on attention measures, but since 2016 studies investigating stress have increased substantially; studies of ARM alone have decreased and studies conjointly considering ARM and SRM have increased (Figure 2).

Figure 2. Studies investigating green space effects on attention and stress in children



Notes:

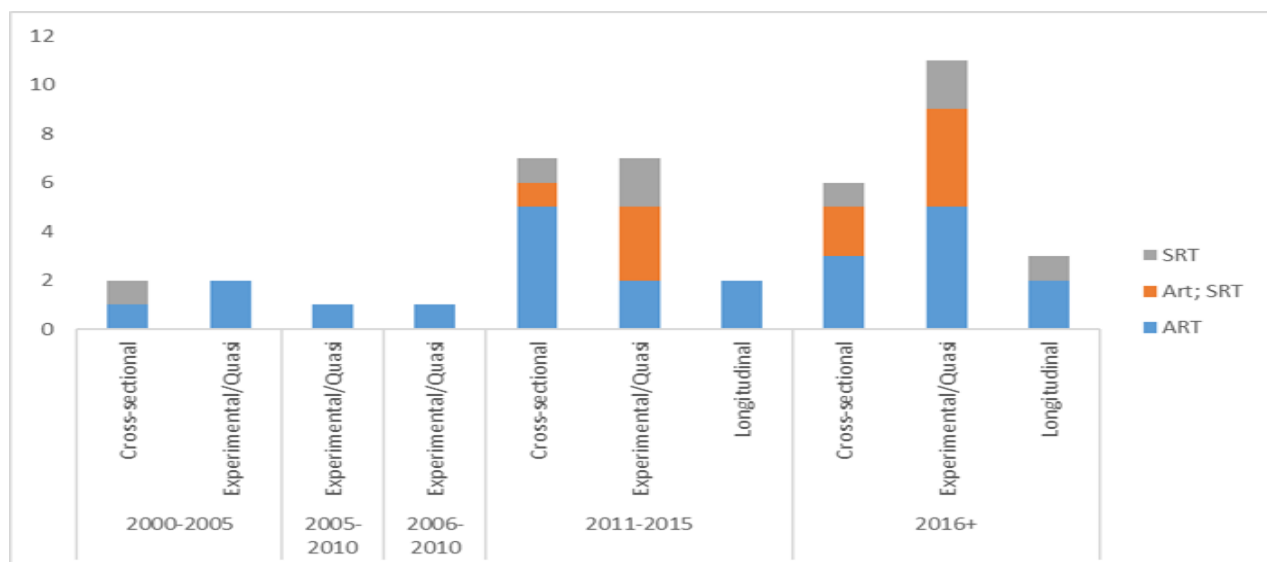
ART = Attention Restoration Theory

SRT = Stress Reduction Theory

Study Descriptions

Across studies there were 163,030 participants (ARM = 88,790, SRM = 71,807; ARM & SRM = 2,433), of which 41,804 were female (ARM = 40,060; SRM = 488; ARM & SRM = 1,256) and 43,892 were male (ARM = 42,228; SRM = 503; ARM & SRM = 1,161) (several studies did not report gender-level data) (see Appendix A and B). The mean age of participants was 10 years (ARM = 9.1; SRM = 10.7; ARM/SRM = 11.5) (Appendix A). The majority of studies used experimental or quasi-experimental designs (K = 22; ARM = 4; SRM = 7; ARM/SRM = 7), followed by cross-sectional (K = 15; ARM = 9; SRM = 3; ARM/SRM = 3), and longitudinal designs (K = 5; ARM = 4; ARM/SRM = 0; SRM = 1) (Table 1). Early studies (2000 – 2010) were primarily experimental ARM studies (K = 4) with one cross-sectional study. Recent years have witnessed an increase in cross-sectional and longitudinal studies (Total = 18; ARM = 12; SRM = 3; ARM/SRM = 3), with continued growth in experimental/quasi-experimental studies (Total = 18; ARM = 7; SRM = 4; ARM/SRM = 7) (see Figure 3). The majority of studies came from European countries (K = 26) followed by the United States (K = 14), Canada (K = 1) and Australia (K = 1) (Table 1). Most studies (K = 21) investigated a range of child stages (Early to Middle Childhood = 8, Early Childhood to Adolescence = 5, Middle Childhood to Adolescence = 4, Adolescence to Early Adulthood = 1, Birth to Adolescence = 1, Toddler to Early Childhood = 2). Seven studies focused on Early Childhood, eight on Middle Childhood, five on Adolescents, and one on Infants/Toddlers (ARM/SRM) (Table 1). Table 2 provides synopses of methodological details and the primary study findings.

Figure 3. Changes in research designs of green space effects on attention and stress in children, 2000-2018



Notes:

ART = Attention Restoration Theory

SRT = Stress Reduction Theory

Table 1. Study design, region and developmental stages of sample in studies of green space effects on attention and stress in children

	Total Studies		Attention Studies		Stress Studies		Attention/Stress Studies	
	K	%	K	%	K	%	K	%
Study Design								
Cross-sectional	15	35.71	9	37.50	3	37.50	3	30.00
Experimental/Quasi-experimental	22	52.38	11	45.83	4	50.00	7	70.00
Longitudinal	5	11.90	4	16.67	1	12.50	0	0.00
Total	42	100.00	24	100.00	8	100.00	10	100.00
Region								
Australia	1	2.38	1	4.17	0	0.00	0	0.00
Canada	1	2.38	1	4.17	0	0.00	0	0.00
Europe	27	64.29	13	56.17	5	62.50	9	90.00
US	13	30.95	9	37.50	3	37.50	1	10.00
Total	42	100.00	24	100.00	8	100.00	9	100.00
Stage of Development								
Infancy/Toddlerhood	1	2.38	0	0.00	0	0.00	1	10.00
Early Childhood	7	16.67	6	25.00	0	0.00	1	10.00
Middle Childhood	8	19.05	4	16.50	3	37.50	1	20.00
Adolescence	5	11.90	0	0.00	1	12.50	4	40.00
Range of Stages	21	50.00	15	62.5	4	50.00	2	20.00
Total	42	100.00	24	100.00	8	100.00	10	100.00

Attention Measures

Investigations of green space and attention in children were based on a mix of objective and subjective attention measures. Five studies were published using objective measures before 2010 (ARM = 5; ARM/SRM = 0), 13 studies (ARM = 9; ARM/SRM = 4) were reported from 2011 to 2015, and 16 since 2016 (ARM = 10; ARM/SRM = 6) (Tables 2-4; Appendix A and B). Subjective attention measures were primarily rating scales designed to measure perceived aspects of attention skills. The most widely used scales were clinical tools or RDIs measuring inattention and hyperactive traits (K = 12; ARM = 10; ARM/SRM = 2). The most popularly used attention scale was the Strengths and Difficulties (SDQ) ADHD scale (K = 7; ARM = 5; ARM/SRM = 1), a widely used mental health screener that measures attention and hyperactivity traits related to ADHD (Goodman, 1997). Two ARM studies used the Early Childhood Attention Deficit Disorders Evaluation Scale (McCartney, 1995), and three used RDIs. Finally, eight studies (ARM = 5; ARM/SRM = 3) measured perceived restorativeness using several scales designed to explicitly measure hypothesized ART constructs (Bagot, 2004; Bagot, Kuo, & Allen, 2007; Hartig, Korpela, Evans, & Garling, 1997).

Table 2. Overview of measures used across studies of green space effects on attention and stress in children

	Total Studies		Attention Studies		Stress Studies		Attention/Stress Studies	
	K	%	K	%	K	%	K	%
Green Space Measures								
Standardized	4	9.52	2	8.33	2	25.00	0	0.00
Place Based	19	45.24	10	41.67	2	25.00	7	70.00
RDI	5	11.90	4	16.67	0	0.00	1	10.00
RDI and Standardized	1	2.38	0	0.00	1	12.50	0	0.00
Satellite Based	12	28.57	7	29.17	3	37.50	2	20.00
Satellite and RDI	1	2.38	1	4.17	0	0.00	0	0.00
Total	42	100.00	24	100.00	8	100.00	10	100.00
ARM Measures								
Objective/Subjective	5	14.71	3	12.50	0	NA	2	20.00
Objective Only	14	41.18	9	37.50	0	NA	5	50.00
Subjective Only	15	44.12	12	50.00	0	NA	3	30.00
Total	34	100.00	24	100.00	0	NA	10	100.00
SRM Measures								
Objective/Subjective	1	5.56	0	NA	0	0.00	1	10.00
Objective Only	7	38.89	0	NA	2	25.00	5	50.00
Subjective Only	10	55.56	0	NA	6	75.00	4	40.00
Total	18	100.00	0	NA	8	100.00	10	100.00
ARM Objective Measures Only								
No	16	47.06	13	54.17	0	NA	3	30.00
Yes	18	52.94	11	45.83	0	NA	7	70.00
Total	34	100.00	24	100.00	0	NA	10	100.00
ARM Subjective Measures Only								
No	14	41.18	9	37.50	0	NA	5	50.00
Yes	20	58.82	15	62.50	0	NA	5	50.00

Total	34	100.00	24	100.00	0	NA	10	100.00
SRM Objective Measures Only								
No	10	55.56	0	NA	6	75.00	4	40.00
Yes	8	44.44	0	NA	2	25.00	6	60.00
Total	18	100.00	0	NA	8	100.00	10	100.00
SRM Subjective Measures Only								
No	7	38.89	0	NA	2	25.00	5	50.00
Yes	11	61.11	0	NA	6	75.00	5	50.00
Total	18	100.00	0	NA	8	100.00	10	100.00

Notes:

ARM = Attention-Related Measures

SRM = Stress-Related Measures

Table 3. Green space, attention and stress measures in studies of children

Author	Green Space Measurement	Attention Measures		Stress Measures		Other Measures	
		Objective	Subjective	Objective	Subjective	Objective	Subjective
Carrus et al. (2012)	Place-Based: School	RDI - Visual Spatial Task	No	RDI - Behavior Frequencies	No	RDI - Social Interactions	No
Balseviciene et al. (2014)	Satellite: Residential greenness; proximity to city parks	No	SDQ - ADHD	No	Parenting Stress Index Short Form (Abidin, 1995)	No	SDQ EP, PP, CP, Pro
Berto, Pasini, & Barbiero (2015)	Place-Based: Alpine wood	Continuous Performance Tasks (Cornoldi, Gardinale, Masi, & Pettenò, 1996)	Italian Perceived Restoration Scale (Berto, 1998)	Blood pressure; Heart rate	No	No	RDI - Environmental Preference; Connectedness to Nature Scale (Mayer & McPherson-Frantz, 2004)
Kelz, Evans, & Roderer (2015)	Place-Based: School	Attention Network Test (Fan, McCandliss, Sommer, Raz, & Posner, 2002)	Perceived Restoration Scale (Hartig et al., 1997)	Blood pressure; Heart rate	No	No	Basler Well-Being Questionnaire (Juda, 2010)
Akpinar (2016)	RDI: Level of Naturalness	No	Perceived Restoration Scale (Hartig et al., 1997)	No	RDI - Stress	No	RDI - Child Mental Health, Physical Health, and Quality of Life
Greenwood & Gatersleben (2016)	Place-Based: School	Necker Cube Pattern Control (Necker, 1832)	No	Blood pressure; Heart rate	No	No	Zuckerman Inventory of Personal Reactions (Zuckerman, 1977)

Author	Green Space Measurement	Attention Measures		Stress Measures		Other Measures	
		Objective	Subjective	Objective	Subjective	Objective	Subjective
Li & Sullivan (2016)	Place-Based: Classrooms with windows onto green space	Digit Span Forward; Digit Span Backwards (Wechsler, 1981)	No	Electro-cardiogram; Blood volume pulse; Skin conductance; Body temperature	Visual Analogue Scale (Lesage, Berjot, Deschamps, 2012); RDI - Stress; Fatigue	No	RDI - Landscape Preference Measure
Mygind et al. (2018)	Place-Based: School	D2 (Brickenkamp, 1994)	No	Heart rate (Vagal tone)	No	No	No
Van Aart et al. (2018)	Satellite: Residential nature	No	SDQ - ADHD	Cortisol	RDI - Anxiety	No	SDQ - EP, PP, CP, Pro, Tot RDI - Happy, Sad, Angry, Total Negative
Wallner et al. (2018)	Place-Based: Parks with differing levels of trees	D2-R (Brickencamp, Schmidt-Atzert, & Liepmann, 2010)	No	No	Nitsch - Tension (Nitsch, 1976)	No	Nitsch - Recuperation, Mood, Action Readiness, Exertion Readiness, Alertness

Notes:

ADHD = Attention Deficit Hyperactivity Disorder

CP = Conduct Problems

EP = Emotion Problems

PP = Peer Problems

Pro = Prosocial

RDI = Researcher Designed Instrument

SDQ = Strengths and Difficulties Questionnaire

Tot = Total Score

Table 4. Green space, attention measures, and other measures in reviewed studies

Author	Green Space Measurement	Attention Measures		Other Measures	
		Objective	Subjective	Objective	Subjective
Wells (2000)	Standardized: Naturalness scale instrument (Evans, Wells, Chan, & Saltzman, 2000)	No	Attention Deficit Disorders Evaluation Scale (McCartney, 1995)	No	No
Faber Taylor, Kuo, & Sullivan (2002)	RDI: Amount of nature viewed from residence	Symbol Digit Modalities Test (Smith, 1968); Digit Span Backwards (Wechsler, 1955); Alphabet Backwards (Cimprich, 1992); Necker Cube Pattern Control (Necker, 1832)	No	Matching Familiar Figures Test (Kagan, 1966); Stroop Test (Dyer, 1973); = Category Matching (Melnik & Das, 1992) Delay Gratification Task (Rodriguez, Mischel, & Shoda, 1989)	No
Kuo & Faber Taylor (2004)	RDI: Common child activities in green areas	No	RDI - ADHD	No	No
Mårtensson et al. (2009)	Standardized: Outdoor Play Environment Categories (OPEC) (Mårtensson, 2004; Mårtensson & Boldemann, 2008)	No	Early Childhood Attention Deficit Disorders Evaluation Scales – Hyper/Impulsive, Attention (McCartney, 1995)	No	Sky View Factors
Faber Taylor & Kuo (2009)	Place Based: Urban park	Digit Span Backwards (Wechsler, 1981; Vigilance Task Model (Gordon, McClure, & Aylward, 1996)	No	Stroop Color-Word Test (Dodrill, 1978)	Researcher Designed Instrument Walks were Fun, Relaxing, Interesting, Scary, Boring, Weird, or Uncomfortable
Faber Taylor & Kuo (2011)	RDI: Places children mostly played in last week and where play typically occurred	No	RDI - ADD or ADHD	No	No

Author	Green Space Measurement	Attention Measures		Other Measures	
		Objective	Subjective	Objective	Subjective
van den Berg & van den Berg (2011)	Place Based: A farm in a green natural setting	Opposite Worlds (Manly et al., 2001)	Perceived Restoration Scale (Hartig et al., 1997); RDI - Behavioral observations: Inattention and Impulsive/Hyper	No	Mood Test (van den Berg, Hartig & Staats, 2007); RDI - Behavioral observations: Social, Cooperative, Enthusiasm, Aggressive; Pediatric Quality of Life (Varni, Seid, & Kurtin, 2001)
Amoly et al. (2014)	Satellite: Proximity of residence and school to green space	No	SDQ - ADHD (Inattention and Hyperactive); RDI - DSM-IV ADHD	No	SDQ - EP, PP, CP, Pro
Flouri, Midouhas, & Joshi (2014)	Satellite: Neighborhood green space	No	SDQ - ADHD	No	SDQ EP, PP, CP, Pro; RDI - Adverse Life Events
Markevych et al. (2014)	Satellite: Residential distance from urban green spaces	No	SDQ - ADHD	Blood pressure; Body mass index; Hypertension	SDQ EP, PP, CP)
Bagot et al. (2015)	RDI: Ratings of school playground photographs; cubic meters of vegetation; grass covering	No	Perceived Restorativeness Components Scale for Children II (Bagot, 2004; Bagot et al., 2007)	No	Positive and Negative Affect Scale (Crook, Beaver, & bell, 1998); Perceived Affordances Scale (Kytta, 2002); Play Diary; Social Interaction Task
Collado & Corraliza (2015)	Standardized: Schools green and non-green based on the Nearby Naturalness Observation Scale (Wells, 2000)	No	Perceived Restorativeness Components Scale for Children II (Bagot et al., 2007)		Children's Environmental Perceptions Scale (Larson et al., 2011; RDI - Ecological Behavior)
Dadvand et al. (2015)	Satellite: School, residential, commuting and total green space	N-Back Working Memory task (Jaeggi, Buschkuhl, Perrig, & Meier, 2010); Attention Network Test (Fan et al., 2002)	No	No	No

Author	Green Space Measurement	Attention Measures		Other Measures	
		Objective	Subjective	Objective	Subjective
Dadvand et al. (2017)	Satellite: Residential	Connor – Kiddie Continuous Performance Task (Conners, 2000); Attention Network Test (Fan et al., 2002)	No	No	No
Kuo et al. (2017)	Place Based: Outdoor class	No	RDI	No	No
Müller & Liben (2017)	Place Based: Green kindergartens	Boxes Task (WM), Continuous Performance Task (Kerns & McInerney, 2007)	No	Head Shoulders Knees and Toes Task (Ponitz, McClelland, Matthews & Morrison, 2009); Test of Gross Motor Development (Ulrich, 2000); Physical Activity	Pictorial Scale of Perceived Competence and Social Acceptance for Young Children (Harter & Pike, 1984); Social Skills Rating Scales (Gresham & Elliot, 1990) RDI – Nature Relatedness
Richardson, Pearce, Shortt, & Mitchell (2017)	Satellite: Park and residential green space	No	SDQ - ADHD	No	
Schutte, Torquati, & Beattie (2017)	Place Based: Urban walks	Spatial Working Memory (Schutte & Spencer, 2002); Digit Span Backwards (Wechsler, 1981); Go/No-Go (Wiebe, Sheffield, & Andrews Espy, 2012)	No	No	No
Torquati et al. (2017)	Place Based: Green outdoor setting	Spatial Working Memory (Schutte & Spencer, 2002); Digit Span Backwards (Wechsler, 1981); Go/No-Go (Wiebe et al., 2012); Continuous Performance Tasks (Wiebe et al., 2011); EEG	No	No	No
Ulset, Vitaro, Brendgen, Bekkhus, & Borge (2017)	Place Based: Daycare facilities	Digit Span Backwards (Wechsler, 1981)	SDQ – ADHD (Broke into Hyperactive and Inattention subscales)	No	No

Author	Green Space Measurement	Attention Measures		Other Measures	
		Objective	Subjective	Objective	Subjective
Dzhamabov et al. (2018)	Satellite: Urban green space RDI: Self-reported green space	No	Perceived Restoration Scale (Hartig et al., 1997)		General Health Questionnaire (Georgieva, 2010); Short Questionnaire to Assess Health-enhancing physical activity (Wendel-Vos, Schuit, Saris & Kromhout, 2003); Biological Effects of Noise scale (Guski, Felscher-Suhr, & Schuemer, 1999); Perceived Neighborhood Social Cohesion Questionnaire (Dupuis, Baggio, & Gmel, 2017)
Largo-Wright et al. (2018)	Place Based: Schools	RDI – Off Task Behavior (Counts)	No	RDI –Well Being and Happiness	No
Markevych et al. (2018)	Satellite: Post code area	No	ICD - ADHD	NO ² (covariate)	
van Dijk-Wesselius et al. (2018)	Place Based: Schools RDI: Student-perceived naturalness	Digit Letter Substitution Test (Natu & Agarwal, 1995); Sky Search task subscale from the Test of Everyday Attention for Children (Manly et al., 2001)	Perceived Restorativeness Components Scale for Children II (Bagot, 2004; Bagot et al., 2007)	Moderate to Vigorous Physical Activity	Pediatric Quality of Life Scale (Varni et al., 2001); SDQ-Pro; Social Orientation Choice Card (Knight, 1981); RDI - Schoolyard Likeability, Attractiveness

Notes:

ADHD = Attention Deficit Hyperactivity Disorder

CP = Conduct Problems

EP = Emotion Problems

PP = Peer Problems

Pro = Prosocial

RDI = Researcher Designed Instrument

SDQ = Strengths and Difficulties Questionnaire

Tot = Total Score

When measuring attention with objective measures, the most common approach was to use working memory (WM) tasks (Total = 8; ARM = 7; ARM/SRM = 1). The most commonly used objective WM measure was the digit span backwards wherein an adult tester verbally relays a series of number to a child and the child is to repeat them backwards (Wechsler, 1955; 1981). Similar WM tasks like the Alphabet Backwards test were also found (Cimprich, 1992). Several other WM tests were also commonly seen across studies including digit span forward, a spatial WM test, and the N-back WM test. Aside from WM tasks, four studies (ARM = 3; ARM/SRM = 1) used different versions of the Continuous Performance Task. Further, two studies (ARM = 1; ARM/SRM = 1) reported findings on the Attention Network Task and the D2 task (Brickencamp, 1994; Brickenkamp, Schmidt-Atzert, & Liepmann, 2010; Fan et al., 2002). Other unique objective ARM in single studies included the Necker Cube task, Opposite Worlds Test, and the Vigilance Task from the Gordon Diagnostic System Model, the Digit Letter Substitution Test, and the Sky Search task subscale from the Test of Everyday Attention for Children (Gordon et al., 1996; Manly et al., 2001; Natsu & Agarwal, 1995).

Stress Measures

Several investigations reported objective stress measures (K = 8; SRT = 2; ARM/SRT = 6) (Tables 2, 3 and 5). Five stress studies reported data on blood pressure and heart rate-related outcomes. One of these five studies also reported data on electrocardiogram readings, skin conductance, and body temperature. Three other studies reported data on cortisol. Stress studies primarily used subjective scales for outcomes (K = 11; SRM = 6; ARM/SRM = 5). The most common approach was to report outcomes with RDIs. Other studies reported un-replicated single measures including the Parenting Stress Index Short Form, the Perceived Stress Scale, the Mood Adjective Checklist – Stress subscale, the Lewis Stressful Life Events Scale, and Rutter Child Behavior Questionnaire Distress Scale (Abidin, 1995; Cohen, Kamarck, & Mermelstein, 1983; Lewis, Seigel, & Lewis, 1984; Matthews, Jones, & Chamberlain, 1990; Rutter, Tizard, & Whitmore, 1970). These scales measure different aspects of stress. For example, the Lewis Stressful Life Scale measures the number of events that commonly lead to feelings of stress, the Perceived Stress Scale and Mood Adjective Checklist – Stress subscale measure typical stress levels, and the Rutter Distress Scale measures clinically relevant measures of acute distress.

Measures of Green Space

Most studies used place-based metrics of green space (k = 19 [ARM = 10, SRM = 2, ARM/SRM = 7]), followed by satellite-based technology measures (k = 12 [ARM = 7, SRM = 3, ARM/SRM = 2]), RDIs (k = 5 [ARM = 4, SRM = 0, ARM/SRM = 1]), and validated instruments (k = 4 [ARM = 2, SRM = 2, ARM/SRM = 0]). One attention study used both satellite and RDI metrics and one stress study used both an RDI and previously published instrument to measure green space (see Tables 2-5).

Table 5. Green space, stress measures, and other measures in reviewed studies

Author	Green Space Measurement	Stress Measures		Other Measures	
		Objective	Subjective	Objective	Subjective
Wells & Evans (2003)	Standardized: Naturalness scale instrument (Evans et al., 2000)	No	Lewis Stressful Life Events Scale (Lewis et al., 1984); Rutter Child Behavior Questionnaire Distress Scale (Rutter et al., 1970)	No	Global Self-Worth subscale of the Harter Competency Scale (Harter, 1982)
Corraliza et al. (2012)	Standardized: Nearby Nature Observational Scale (NNOS; Collado, 2009) RDI: Perceived Nature Questionnaire	No	Perceived Stress Scale (Martorell, Sánchez, Miranda, & Escrivá, 1990); Stressful Events Questionnaire (Lewis et al., 1984)	No	No
Roe & Aspinall (2011)	Place-Based: Forest education program	No	Mood Adjective Checklist – Stress (Matthews et al., 1990)	No	Mood Adjective Checklist – Energy, Hedonic Tone, Anger
Soderstrom et al. (2013)	Standardized: OPEC measures (Boldemann et al., 2006; 2011)	Cortisol	No	Body Mass Index, Waist Size, Sleep	RDI - Well-being; Health
Feda et al. (2015)	Satellite: Residential green space areas and park access; % of land devoted to parks	No	Perceived Stress Scale (Cohen et al., 1983; Martorell et al., 1990)	Activity Monitor (Not Outcome)	No
Dettweiler, Becker, Auestad, Simon, & Kirsch (2017)	Place-Based: Outdoor class	Cortisol	No	Activity Monitor (Outcome)	No
Larson et al. (2018)	Satellite: Zip-code level green space	No	RDI - Anxiety Severity	No	No
Mennis, Mason & Ambrus (2018)	Satellite: Measures of green space	No	RDI - Stress	No	No

Discussion

This scoping review of green space effects on attention and stress measures in children helps to clarify the current state of the literature for researchers interested in extending this work. There are diverse attention and stress measures used across the literature, with both subjective and objective measures commonly used. Green space measures also vary and include simple binaries, green spaces measured with rating scales, and satellite-based measures with locally refined

metrics. Researchers should take care framing findings around dominant theories as attention and stress are complex and dynamic constructs. The degree to which the diverse identified objective and subjective attention and stress measures relate to these theories is not clear.

Green Space and Attention

Studies of green space in children most frequently use attention measures with three clear measurement traditions identified: a subjective Kaplan ART restorativeness tradition, a subjective ADHD measurement tradition, and an objective measurement tradition. Subjective measures of Kaplan's ART were least commonly found in the literature. These ART attention measures were used as outcomes in a number of experimental and cross-sectional studies (Akpınar et al., 2016; Berto, Pasini, & Barbiero, 2015). Further, the use of ADHD scales has grown in recent years and these are primarily used in cross-sectional or longitudinal correlational studies, but not in experimental studies (Ulset et al., 2017; van Aart et al., 2018).

Moving forward, researchers should take note that the correspondence between attention measures from the ART tradition with ADHD scales or objective attention measures is not clear. Despite several studies measuring perceived restorativeness along with subjective ADHD and objective attention measures, only one reported effects on both perceived restoration and an objective attention measure (Berto et al., 2015; Kelz et al., 2015; van den Berg & van den Berg, 2011; van Dijk-Wesselius et al., 2018). These few studies conjointly considering Kaplan ART restoration measures alongside ADHD and objective attention metrics do not necessarily provide strong evidence that metrics used across studies are comparably sensitive to green space. Unfortunately, none of the studies identified during our search correlated restoration constructs with ADHD scales or objective attention measures. A major area of research that would help facilitate understanding of the literature is to determine the degree to which ADHD and objective attention measures correlate with perceived restoration scales. It may be that, similar to other areas of attention measurement, these different attention measures reflect fundamentally different constructs (Limbers et al., 2017; Snyder et al., 2015; Toplak et al., 2013). As such, using ADHD and objective attention scales as evidence supporting ART should be considered tenuous until research supports that these measures are meaningfully related.

Greater care should also be taken with interpreting attention measures used in the ADHD green space literature. For example, a number of studies used the SDQ-ADHD subscale, which includes a mixture of inattentiveness and activity items (Goodman, 1997). Since green space exposure predicts greater mobility and activity levels, ADHD scales combining inattention and activity items may include two constructs that are independently affected by green space (Gray et al., 2015). This may not be serious concern as the implicit notion of "activity" items on ADHD scales refers to actions occurring in inappropriate contexts, but does speak to the need for greater care when using subjective ADHD scales as outcomes. At a minimum, more research is needed to clarify the distinct relation between green space, attention, and activity.

This review also identified diverse objective attention measures across studies. Working memory was the most commonly investigated with some studies showing sensitivity to variation in green spaces (Dadvand et al., 2015; Li & Sullivan, 2016; Schutte et al., 2017). However, other studies reported non-significant relationships when measuring the impact of green space on the digit span and the Boxes Task (Müller & Liben, 2017; Torquati et al., 2017; Ulset et al., 2017). Similarly, the Attention Network Task displayed significant relationships to measures of green space in two studies (Dadvand et al., 2015; Kelz et al., 2015). Furthermore, the D2 measure and Continuous Performance Task also had inconsistent relationships with green space across studies (Mygind et al., 2018; Schutte et al., 2017; Torquati et al., 2017; Wallner et al., 2018). When considered in light of the weak and non-existent effects of natural environments on many objective attention measures in adults, interpretation of research in this area warrants caution (Moens et al., 2019).

A close inspection of the Schutte et al. (2017) and Torquati et al. (2017) studies displays how interpretation of the objective measurement literature requires a nuanced perspective. Schutte et al. (2017) found that green space was unrelated to Continuous Performance Task scores, but Torquati et al.'s (2017) follow-up study showed that green space exposure significantly correlated with attention-related EEG activity during this task, despite non-significant associations with continuous performance. Thus, green space exposure was associated with children harnessing fewer neurological resources to perform at the same level. Since attention is a multi-faceted phenomenon undergirded by complex brain-based neurophysiology, current measurement approaches may not be refined enough to capture neuro-cognitive processes impacted by green space (Morales et al., 2016). Insights from researchers are needed in this literature to further refine the measurement of attention.

Finally, it is interesting to note that objective measurements were primarily used in experimental and quasi-experimental studies in which objective, and occasionally ADHD, attention measures were collected (Faber Taylor & Kuo, 2009; Torquati et al., 2017; Schutte et al., 2017; van den Berg & van den Berg, 2011). How the type of measurement becomes associated with experimental versus correlational designs could have to do with the disciplines of researchers conducting the studies. For example, using shorter screening tools and/or single items for constructs is field normative in public health where large N correlational community, state, or national studies are common (Larsen et al., 2019). Experimental studies, on the other hand, may be more likely to have team members that are cognitive or clinical psychologists trained in implementing objective attention assessments (Torquati et al., 2017; Schutte et al., 2017). This is important as some types of measurement may be more or less sensitive to environmental conditions. Of note, objective attention and subjective ADHD scales may be more likely to measure psychological "traits" that could be less susceptible to transient environmental effects. Further, it may be that ART measures are more like psychological "states" that are thought to be more easily impacted by the environment (Fridhandler, 1986). However, the distinction between state and trait measures is quite complicated (Ilkowska, & Engle, 2010; Litson, Geiser, Burns, & Servera, 2018). Ultimately, whether states or

traits, the field will need to take greater care determining what aspects of attention are being measured and the degree to which objective, ADHD, and ART measures are optimally sensitive as outcomes.

Green Space and Stress

Objective and subjective measurement traditions were also identified in the green space-stress literature. A number of studies from the objective measurement tradition investigated green space effects on heart rate and blood pressure (Berto et al., 2015; Kelz et al., 2015). A handful of studies used objective neurophysiological or hormonal measurement (Van Aart et al., 2018). Studies from the subjective tradition reflected a heterogeneous mix of stress rating scales. The most common subjective stress outcomes were researcher-designed instruments which differ in terms of time frame considered and number of Likert selections (Akpınar et al., 2016; Larson et al., 2018; Mennis, Mason, & Ambrus, 2018; Van Aart et al., 2018). Critically, no stress study has been replicated with the same subjective measurement. Considering how common it is for studies to fail replication, green space research using subjective stress measures in children should be considered preliminary. Furthermore, like subjective ADHD and ART scales, more research is needed to determine the degree to which these stress scales are measuring the same or similar constructs. That said, considering the research base on the relationship between objective and subjective stress measures, cross-study comparisons seem more tenable for stress than for attention studies (Eldar et al., 2008; Morales et al., 2016; Tu et al., 2007; White et al., 2017).

The stress objective measures are more comparable across studies and consideration of seemingly conflicting findings point to the importance of comparative study environments. For example, Berto et al. (2015) and Greenwood and Gatersleben (2016) reported similar levels of heart rate decreases when comparing green space to indoor conditions. However, Berto et al. (2015), uniquely found that heart rate decreased to a greater degree for children in green space conditions compared to non-green space outdoor conditions. Though these studies differ methodologically in a number of ways, it may be that a comparison of green versus non-green outdoor spaces provides a more optimal contrast than outdoor to indoor conditions when heart rate is the outcome measure.

Green Space Measures

Green space measurement in child-focused studies has evolved over the last two decades. Early studies primarily relied on rating instruments to quantify the amount of green space surrounding school and residential areas (Faber Taylor, Kuo, & Sullivan, 2002; Wells, 2000; Wells & Evans, 2003). The last decade has witnessed a proliferation of place-based and satellite-based green metrics arising from different research traditions (Berto et al., 2015; Carrus et al., 2012; Davand et al., 2015; Dzhamabov et al., 2018; Mennis et al., 2018; Wallner et al., 2018). In the present review, place-based metrics were primarily found in quasi-experimental and experimental studies, whereas satellite-based metrics were found almost exclusively in non-experimental cross-sectional and longitudinal studies aimed at investigating the amount of green space in correlational analyses. An interesting

area for advancing our knowledge will come from multi-site experimental studies incorporating satellite-based metrics of green space to capture meaningful between-site variances.

Future Directions

This scoping review outlines several important future directions for researchers to consider pursuing when investigating green space effects on children. Greater care should be taken in the area of measurement, particularly in determining the relationship between subjective and objective measures. Furthermore, research on the neurophysiological underpinnings of objective attention seems a particularly fruitful line of research leading to nuanced understanding of the impact of green space on attention. Finally, perspectives from researchers are needed to speak to the complex relationships between attention and stress. It is notable that studies conjointly investigating attention and stress together report more non-significant relationships (Balseviciene et al., 2014; Carrus et al., 2012). Furthermore, some researchers have experimentally induced stress and attention-depletion using methods such as social stress, puzzles, and cognitive tasks (Greenwood & Gatersleben, 2016; Kirschbaum et al., 1993; Li & Sullivan, 2016; Faber Taylor & Kuo, 2009). Not all tasks have published evidence displaying their effects on stress and attention, and future research might seek to address under what conditions these types of tasks are appropriate.

Limitations and Conclusions

The findings reported here are limited in a number of ways. First, limiting our search to studies measuring attention and stress likely screened out studies related to other interesting outcomes. In particular, our search methodology screened out numerous studies related to health, educational outcomes, and quality of life, each with recent child-focused reviews (Alderton et al., 2019; Browning & Rigolon, 2019; Mygind et al., 2021; Gray et al., 2015; Kabisch et al., 2017; Lambert et al., 2018; Vanaken & Danckaerts, 2018). Our findings are also limited by the categories of measurement we chose for analysis. For example, a recent review by Mygind and colleagues (2021) on green space and socioemotional functioning in children includes many studies reviewed here, but provides slightly different categories for attention and stress. While our focus helps frame findings according to the two popular frameworks and measurement considerations, Mygind et al.'s (2021) study is much broader in scope, less measurement focused, and goes deeper into study design than does this review. Additionally, by allowing data from studies whose average age was under 18 we may have inadvertently included findings from primarily adult population studies in a few instances. Finally, considering the questionable congruence of the diverse outcome measures, a meta-analysis is not currently considered appropriate.

This scoping review shows that the number of reports on the relation between green space, attention, and stress has dramatically grown in the last decade. Attention and stress measures are diverse and there are strengths to be gleaned across traditions, as well as weaknesses of which to be aware. Green space-attention studies in children have evolved three distinct measurement traditions. The degree to which these measurement traditions relate to each other is unclear.

In particular, research displaying how ART measures correlate with ADHD measures and objective attention measures is needed. Stress research has a fairly robust objective measurement tradition, but has not yet identified a stable set of subjective measures replicated across studies. The lack of replication of subjective stress measures prevents a meaningful cross-comparison of studies. Ultimately, research outlining the relationships between objective and subjective attention measures will help the field determine the comparability of studies to date.

Finally, researchers should consider the strengths of blending methodologies. For example, experimentalists rely primarily on place-based binary (green/non-green) metrics, whereas cross-sectional researchers tend to use satellite-based metrics. With larger samples, green/non-green settings could be geocoded for relevant environmental factors such as canopy density, surrounding shrubbery, and open non-canopied green spaces. Further, cross-sectional studies might take a “case-control” approach, comparing types of terrains to determine relative environmental effects within environmental categories (Armenian, 2009). Collectively, cross-breeding these traditions would result in a more refined understanding of environments and yield fine-tuned, testable hypotheses for future research.

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Notes: * = empirical study identified in systematic review

^ = measurement study cited in article identified in systematic review

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Appendix A.**Table 6. Participant characteristics in studies of green space effects on attention and stress in children**

	k	Mean	SD	Mdn	Min	Max	Total
Total							
Total	42	3881.7	14749.0	175.5	10	70817	163030
Male	36	1219.2	5650.0	91.0	9	34100	43892
Female	36	1161.2	5423.9	84.5	2	32723	41804
Gender Missing	6	NA	NA	NA	NA	NA	NA
Mean Age	42	10.0	3.6	9.9	2.3	17.89	NA
Attention and Stress							
Total	10	243.3	436.1796	107	16	1468	2433
Male	9	129	225.1	54	19	724	1161
Female	9	139.55	230.15	64	18	744	1256
Gender Missing	1	NA	NA	NA	NA	NA	NA
Mean Age	10	11.486	4.825184	11.6	2.3	17	NA
Attention Only							
Total	24	3699.58	13522.42	413.5	10	66823	88790
Male	20	2111.40	7542.92	296.5	9	34100	42228
Female	20	2003	7244.99	212.5	2	32723	40060
Gender Missing	4	NA	NA	NA	NA	NA	NA
Mean Age	24	9.095	2.98	9.4	4.4	17.89	NA
Stress Only							
Total	8	8975.9	24987.8	170.5	18	70817	71807
Male	7	71.9	53.6	76.0	15	172	503
Female	7	69.7	55.9	81.0	3	165	488
Gender Missing	1	NA	NA	NA	NA	NA	NA
Mean Age	8	10.7	2.9	11.3	4.48	13.5	NA

Appendix B.

Table 7. Study design details and synopses of studies investigating green space effects on attention and stress in young people

Study	Design	Synopsis
Wells (2000)	Quasi-experimental (Within): (a) Pre-move, (b) Post-move; Correlation, Linear Regression	ATTENTION: Pre-move greenness correlated with pre-move Attention Deficit Disorders Evaluation Scale scores; pre-move naturalness predicted post-move Attention Deficit Disorders Evaluation Scale scores; change in greenery predicted post-move Attention Deficit Disorders Evaluation Scale scores STRESS: NA Other: NA Covariates: Pre-move Attention Deficit Disorders Evaluation Scale scores, Housing Quality Study Population: N = 17 (Male = 9; Female = 8); Early Childhood to Adolescence (6-18 Years, M = 9.5); United States
Faber Taylor et al. (2002)	Cross-sectional; ANOVA; Linear Regression	ATTENTION: Green environments associated with better attention for girls on summary index (Symbol Digit Modalities Test, Digit Span Backwards, Alphabet Backwards, and Necker) STRESS: NA Other: Green environments associated with better inhibition in girls on separate measures of, and a summary index (Matching Familiar Figures Test, Stroop, Category Matching); Green environments associated with better delay gratification and self-discipline (comprised of Attention and Inhibition summary indexes with Delay Gratification) Covariates: Age, Gender Study Population: N = 169 (Male = 91; Female = 78); Early Childhood to Middle Childhood (5-18 Years, M = 11.5); United States
Wells & Evans (2003)	Cross-sectional Correlational, Linear Regression	ATTENTION: NA STRESS: Green space predicted child Rutter Child Behavior Distress scale scores; there was a significant greenness X stress interaction indicating that green space moderate the relationship between Lewis Stressful Life Events Scale and the Rutter Child Behavior Distress scale Other: Green space predicted child Self-Worth; there was a significant green X stress interaction indicating green space moderated relationship between the Lewis Stressful Life Events Scale on Self-Worth. Covariates: Income

Study	Design	Synopsis
		Study Population: N = 337 (Male = 173; Female = 165); Middle Childhood (3 rd -5 th grade, M = 9.2); United States
Kuo & Faber Taylor (2004)	Cross-sectional; Repeated Measure ANOVA, T-tests	ATTENTION: Green activities associated with reduced RDI-ADHD symptoms when children alone, in dyads or larger groups STRESS: NA Other: NA Covariates: Gender, Age, income, Community Type (e.g., urban, rural), Region, Diagnosis, Case Severity, Comorbid Conditions Study Population: N = 406 (Male = 322; Female = 84); Early Childhood to Adolescence (5-18 Years, M = 11.5); United States
Mårtensson et al. (2008)	Quasi-Experimental (Between): (a) High OPEC Schools, (b) Low OPEC Schools; Linear Mixed Models	ATTENTION: Early Childhood Attention Deficit Disorder Evaluation Scale Inattention scores, but not Activity scores, were higher in greener schools when all schools included; both Inattention and Activity were higher when schools that had children outside all day were excluded STRESS: NA Other: NA Covariates: SES, Maternal Education, Child Sleep, Child Activities, Child Contentment with Preschool, BMI, Physical Activity Study Population: N = 198 (Male = 113; Female = 85); Early Childhood (4.5-6.5 Years, M = 5.26); United States
Faber Taylor & Kuo (2009)	Experimental (Within, Randomized, Attention Manipulation): (a) Green Park, (b) Downtown, (c) Neighborhood walks; ANOVA	ATTENTION: Digit Span Backwards scores higher after green walk compared to downtown or neighborhood STRESS: NA Other: No significant findings Covariates: NA Study Population: N = 17 (Male = 15; Female = 2); Early Childhood (7-12 Years, M = 9.2); United States
Faber Taylor & Kuo (2011)	Cross sectional; ANOVA and Correlations	ATTENTION: Green spaces had greater relations with RDI-ADHD symptoms than indoor or built spaces; children playing in canopy covered spaces had higher symptoms than those in grassy alone; children with RDI-ADHD open grass associated with lower symptoms; for non-hyper ADD children canopy and grassy condition were associated with lower symptoms STRESS: NA Other: NA Covariates: Family Income, Gender, Presence of Hyperactivity

Study	Design	Synopsis
		Study Population: N = 421 (Male = 335; Female = 86); Early to Middle Childhood (7 – 12 Years; Mdn = 11.5); United States
Roe & Aspinall (2011)	Quasi-experimental (Between); ANOVA	ATTENTION: NA STRESS: borderline for Mood Adjective Checklist -Stress Other: Students in outdoor settings showed improvements in Mood Adjective Checklist – Energy, Hedonic Tone, and Anger; Covariates: Good/Bad behavior children Study Population: N = 18 (Male = 15; Female = 3); Middle Childhood to Adolescence (Years 1-2 Scottish Senior School, M = 11.0); Scotland
van den Berg & van den Berg (2011)	Experimental (Between): (a) Green farm, (b) Non-green farm; ANOVA	ATTENTION: Perceived Restorativeness Scale scores greater in green farm condition STRESS: NA Other: No significant findings Covariates: NA Study Population: N = 12 (Male = 10; Female = 2); Middle Childhood to Adolescence (9-17 Years, M = 12.8); Netherlands
Carrus (et al. 2012)	Quasi-experimental (Within): (a) Outside green activities, (b) Inside non-green; Mixture Model ANOVA, t-tests	ATTENTION: No significant findings STRESS: Significant interactions indicated fewer interventions and crying episodes, and greater comforting ease for children in green conditions Other: Greater rates of group play and self-directed during green activities Covariates: None Study Population: N = 16; Infancy/Toddlerhood (18-36 Months, M = 2.3); Italy
Corraliza et al. (2012)	Quasi-experimental (Between): (a) Very natural, (b) Natural, (c) Medium natural, (d) Non-natural schools; ANOVA, t-tests, Correlations	ATTENTION: NA STRESS: Perceived and observed nature negatively correlates with Mood Adjective Checklist stress; interaction analysis indicates that nature moderates effects of the stressors of having nothing to do, parents arguing, and spending little time with parents on reported perceived stress Other: No significant relations found Covariates: NA Study Population: N = 172 (Male = 91; Female = 81); Middle Childhood to Adolescence (10-13 Years, M = 11.3); Spain

Study	Design	Synopsis
Soderstrom et al. (2013)	Quasi-experimental (Between): (a) High OPEC, (b) Low OPEC; MANOVA, ANOVA	ATTENTION: NA STRESS: Waking Cortisol higher in children from high Outdoor Play Environment Category areas Other: More hours sleep for children in higher Outdoor Play Environment Category areas Covariates: xx Study Population: N = 169 (Male = 87; Female = 82); Toddler to Early Childhood (3.5-5.9 Years, M = 4.5); Spain
Amoly et al. (2014)	Cross-sectional; Poisson Mixture Models	ATTENTION: Green space playing time predicted reduced DSM-IV ADHD and inattention scores; distance from greenness predicted lower Strengths and Difficulties Questionnaire ADHD scores; home and school greenness predicted lower DSM-IV ADHD and Inattention scores STRESS: NA Other: Green space playing time predicted Strengths and Difficulties Questionnaire Emotion Problems and Peer Problem scales; distance from greenness predicted lower Strengths and Difficulties Questionnaire Total and Conduct Problems scores Covariates: Gender, Grade, Ethnicity, Pre-term Birth, Breastfed, Tobacco Exposure, Mother Smoked During Pregnancy, Responding Caretaker, Parent Education, Parent Employment, Parent Marital Status, Neighborhood SES Study Population: N = 2,111 (Male = 1,071; Female = 1,040); Early to Middle Childhood (7-10 Years, M = 8.5); Spain
Balseviciene et al. (2014)	Cross-sectional; Linear Regression	ATTENTION: No significant findings STRESS: No significant findings Other: Greenness predicted SDQ Conduct Problem and in high education mother groups; Greenness predicted trend in SDQ Prosocial scale in low education mothers Covariates: Child Age, Child Gender, Maternal Stress, Maternal Age, Maternal Education Study Population: N = 1468 (Male = 724; Female = 744); Early Childhood (4-6 Years, M = 5); Lithuania
Flouri et al. (2014)	Longitudinal; Linear Mixed Modeling	ATTENTION: Park use predicted lower Strengths and Difficulties Questionnaire ADHD scores STRESS: NA Other: Park use predicted lower Strengths and Difficulties Questionnaire Conduct Problems and Peer Problems scores; neighborhood greenery predicted lower Strengths and Difficulties Questionnaire Emotion Problems scores for poorer urban children

Study	Design	Synopsis
		Covariates: Index of Multiple Deprivation, RDI - Adverse Life Events, Gender, Ethnicity, Age Study Population: N = 6,384 (Male = NR; Female = NR); Early to middle Childhood (three waves at 3, 5 and 7 Years, M = 8.5); United Kingdom
Markevych et al. (2014)	Cross-sectional; Generalized Additive Models	ATTENTION: Odds clinically significant Strengths and Difficulties ADHD cut-off increases with distance from nearest urban green space STRESS: NA Other: No significant findings Covariates: Gender, Age, Parent Education, Maternal Age at Birth, Single Parent Status, Screen Time, Time Outdoors, Temperature, Altitude, Urbanization, Particulate Matter, NO₂, Noise Pollution Study Population: N = 1,932 (Male = 994; Female = 938); Middle Childhood (9.4-11.7 Years, M = 10.1); Germany
Bagot et al. (2015)	Quasi-experimental (Within) Pre-Post; Correlations	ATTENTION: Vegetation volume predicted post-test Perceived Restoration Scale scores STRESS: NA Other: Social interactions, Positive affect, and Perceived Affordances predicted post-test Perceived Restoration Scale scores Covariates: Gender, Age, Physical Activity Levels, Playground Size, Amount of Equipment, Positive and Negative Affect Scales, Perceived Affordances, Level of Social Activity Study Population: N = 550 (Male = 253; Female = 297); Middle Childhood (8-11 Years, M = 9.7); Australia
Berto et al. (2015)	Quasi-experimental (Within): (a) Classroom, (b) Playground, (c) Alpine wood; ANOVA, t-tests	ATTENTION: Continuous Performance Task scores higher after alpine condition compared to other conditions; Continuous Performance Task responses faster after alpine condition compared to other conditions STRESS: Blood pressure lower after alpine wood condition compared to playground, but not classroom; Heart rate lower after alpine wood condition compared to playground, but not classroom Other: Alpine wood condition more appealing than other conditions Covariates: Gender, Grade Level Study Population: N = 48 (Male = 19; Female = 29); Middle Childhood (9-11 Years, M = 10); Italy

Study	Design	Synopsis
Collado & Corraliza (2015)	Cross-sectional; Path Analysis, t-tests	ATTENTION: Children in green schools had higher Perceived Restoration Scale Fascination, Being Away (Physically), Being Away (Psychologically), Compatibility, Extent, and Total scores STRESS: NA Other: Environmental attitudes mediated relationship between Perceived Restoration Scale subscales and ecological behaviors; path analysis showing inter-relationship between Perceived Restoration subscale scores, environmental attitudes and ecological behaviors Covariates: NA Study Population: N = 832 (Male = 408; Female = 424); Early to Middle Childhood (6-12 Years, M = 10); Spain
Dadvand et al. (2015)	Longitudinal; Linear Mixed Model	ATTENTION: School greenness and Total Greenness predicted 12 month increases in N-back working memory and improved Attention Network Task scores STRESS: NA Other: Elemental carbon mediated relationship between greenness and N-back working memory and Attention Network Task scores Covariates: Age, Gender, Individual and Area Level SES, Maternal Education, Urban Vulnerability Index Study Population: N = 2,593 (Male = 1,297; Female = 1,296); Early to Middle Childhood (7-10 Years, M = 8.5); Spain
Feda et al. (2015)	Cross-sectional; Correlation, Linear Regression	ATTENTION: NA STRESS: % green Park Area in neighborhood predicted perceived Stress Other: No significant findings Covariates: SES, Activity, Gender Study Population: N = 68 (Male = 32; Female = 36); Middle Childhood to Adolescence (12-15 Years, M = 13.5); United States
Kelz et al. (2015)	Quasi-experimental (Within and Between): (a) Pre (non-Green schoolyards), (b) Post (Greened schoolyards); ANOVA, t-test	ATTENTION: Green schools showed similar increases in Attention Network Task as control school; Perceived Restorativeness Scale Compatibility score increased in green schools, unmeasured in control STRESS: Green schools had greater decreases in Blood Pressure compared to control Other: No significant findings Covariates: Parent Education Study Population: N = 133 (Male = 69; Female = 64; Experimental = 72; Control = 61); Adolescence (13 – 15 Years, M = 14.4); Austria

Study	Design	Synopsis
Akpinar et al. (2016)	Cross-sectional; Linear Regression	ATTENTION: Greenness predicted Perceived Restoration Being Away, Fascination, Coherence, and Compatibility scores STRESS: Perceived Restoration Coherence scale predicted RDI Stress scores; Other: Perceived Restoration Coherence scale related RDI Quality of Life, and Mental Health scores Covariates: Gender; Age; Boarding Student Status; Income; Commuter Status Study Population: N = 223 (Male = 82; Female = 141); Adolescence (12-20 Years, M = 16.1, SD = 1.37); Turkey
Greenwood & Gatersleben (2016)	Quasi-experimental (Between, Random, Attention/Stress Manipulation [Pre-post]): (a) Green outdoor – alone, (b) Indoor – alone, (c) Green outdoor – with friend, (d) Indoor – with friend; (e) Green outdoor – with phone, (f) Indoor – with phone; ANOVA , t-tests	ATTENTION: Significant interaction indicated children concentrated better on Necker task after outdoor condition compared to indoor STRESS: Heart Rate and Blood Pressure reduced in both indoor and outdoor conditions Other: Significant interaction showed that children had greater increase in Positive Affect in outdoor condition compared to indoor; significant interaction showed that children had greatest increase in Positive Affect when outside with friend compared to all other conditions Covariates: Study Population: N = 120 (Male = 54; Female = 66; All Condition = 20 per); Adolescence (16-18 Years, M = 17); United Kingdom
Li & Sullivan (2016)	Experimental (Between, Random, Attention/Stress Manipulation [Pre-Post]): Classrooms with windows to (a) Green space, (b) Barren scenes, (c) No windows; ANOVA, T-tests, Change Score Regression	ATTENTION: Children in classrooms with windows to green space showed greater Working Memory (Digit Span) recovery than barren or no window conditions; green window classrooms predicted changes in Working Memory (Digit Span) recovery STRESS: Children in classrooms with windows to green space showed greater stress reduction (Summary Score: ECG, Blood Volume, Skin Conductance, Body Temperature) than barren or no window conditions; Green classrooms predicted changes in stress Other: No significant findings Covariates: Gender, Age, Race, Chronic Stress Level, Chronic Attention Problems, Landscape Preference Study Population: N = 94 (Male = 41; Female = 53; Green = 32; Barren = 32; No Window = 30); Adolescence (14-18 Years, M = 16); United States

Study	Design	Synopsis
Dadvand et al. (2017)	Longitudinal; Linear Mixed Model	ATTENTION: Lifelong residential greenness associated with lower Conner's Kidde Continuous Performance Task omission errors at age 4-5 and Attention Network Task hit rates at age 7 STRESS: NA Other: NA Covariates: Age, Gender, Pre-term Birth; Maternal Intelligence; Maternal Smoking; Tobacco Exposure; SES, Maternal education, Urban Vulnerability Index (Spanish Ministry of Public Works, 2012) Study Population: N = 1,527 (Male = 794; Female = 733); Birth to Early Childhood (data collected at birth, 4-5, and 7 Years; M = 9.7); Spain
Dettweiler et al. (2017)	Experiment (Between; Randomized): (a) Outdoor Classroom, (b) Traditional Classroom; Linear Mixed Effects Models	ATTENTION: NA STRESS: Children in forest condition had greater Cortisol declines Other: Children in forest condition spent more time engaged in Moderate Vigorous Physical Activity Covariates: NA Study Population: N = 48 (Male = 30; Female = 18); Middle Childhood (9-12 Years, M = 11.2); Germany
Muller et al. (2017)	Quasi-experimental (Within and Between): Pre-Post; ANCOVA	ATTENTION: No significant differences found STRESS: NA Other: Children in green kindergartens showed improvements in reported Assertiveness, Cooperation, Self-control, Social Responsibility, Locomotor Skills and Internalizing Symptoms Covariates: Pre-test scores Study Population: N = 88 (Male = 44; Female = 44); Early Childhood (M = 9.7); British Columbia
Richardson et al. (2017)	Longitudinal; Hierarchical Linear Modeling	ATTENTION: Total green space predicts decreases in Strengths and Difficulties ADHD scores in girls; lack of garden access predicts increase in Strengths and Difficulties Questionnaire ADHD scores in girls and low education households STRESS: NA Other: Green space predicts higher Strengths and Difficulties Questionnaire Prosocial scores in girls and high education households; green space predicts lower Strengths and Difficulties Questionnaire Peer Problems scores in low education households; garden access predicts Strengths and Difficulties Questionnaire Peer Problems, Conduct Problems and Total scores in boys and Total scores in girls; garden access predicts lower Strengths and Difficulties Questionnaire Peer Problems and Total scores in boys and Total scores in low income households; garden access showed interaction with age in high income households on Strength and Difficulties Emotion

Study	Design	Synopsis
		Problems and Total scores where children in households without gardens had greater declines over time Covariates: Gender, Age, Screen Time, Income, Household Education, Scottish Index of Multiple Deprivation Study Population: N = 2,909 (Male = 1,478; Female = 1,431); Early Childhood (4-6 Years, M = 4.9); Scotland
Schutte et al. (2017)	Experimental (Within, Randomized, Attention Manipulation); ANOVA, t-tests, Linear Mixed Models	ATTENTION: Continuous Performance Test reaction time faster after green walks; Improved post green walk in Early Childhood, but not Middle Childhood aged children for Continuous Performance Test <i>d'</i> scores; Spatial Working Memory performance better for preschoolers and boys after green compared to urban walks STRESS: NA Other: NA Covariates: Age, Gender Study Population: N = 67 (Male = 32; Female = 35); Early to Middle Childhood (4-8 Years, M = 6.5); United States
Torquati et al. (2017)	Experimental (Within): (a) Green outdoor and (b) Indoor	ATTENTION: Spatial Working Memory performance better in green settings compared to indoor; EEG readings indicated improved neurological during Continuous Performance Task and Go-No/Go in green settings STRESS: NA Other: NA Study Population: N = 10 (Male = NR; Female = NR); Early to Middle Childhood (6-11 Years, M = 9.3); United States
Ulset et al. (2017)	Longitudinal; Growth Curve Analysis	ATTENTION: Interaction indicates hours spent outdoors in green daycares predicts better Strengths and Difficulties Questionnaire ADHD symptoms and Digit Span Backwards performance as children age STRESS: NA Other: NA Covariates: Gender, Age, SES, Temperament, Family harmony, Parent ADHD symptoms during childhood, Daycare Quality Study Population: N = 562 (Male = 264; Female = 298); Infancy to Early Childhood (five waves collected at 3, 4, 5, 6, and 7 Years; M = 4.4); Norway
Dzhamabov et al. (2018)	Cross-sectional; Linear Mixed Models, Mediation Analysis	ATTENTION: Green space predicted higher Perceived Restoration Scale scores (sum of Being Away and Fascination); Self-reported perceived greenness, visible greenness from home, walking in green space, time in green space, and green space quality predicted higher Perceived Restoration Scale scores STRESS: NA

Study	Design	Synopsis
		Other: Self-reported perceived greenness, visible greenness from home, walking in green space, time in green space, and green space quality predicted higher Social Cohesion; Self-reported perceived greenness, walking in green space, time in green space, and green space quality predicted higher Physical Activity; Self-reported walking in green space and green space quality predicted lower Noise Annoyance; Self-reported visible greenness from home, walking in green space, and green space quality predicted lower perceived Air Quality; Satellite measured green space and perceived greenness, visible greenery, walking in green space and time in green space mediated relationship between Perceived Restoration Scale scores and Social Cohesion; Satellite measured green space and perceived greenness, visible greenery, walking in green space and time in green space mediated relationship between Perceived Restoration Scale scores and Physical Activity Covariates: Age, Gender, Ethnicity, Room Orientation, Residential Duration, Time Spent at Home (Average), SES, Noise Level, Population Density Study Population: N = 562 (Male = 264; Female = 298); Adolescence to Adulthood (15-25 Years, M = 17.9); Bulgaria
Kuo et al. (2018)	Quasi-experimental (Within): (a) Outdoor classroom (b) Indoor classroom; ANOVA, t-test, Bayesian	ATTENTION: Green classes resulted in children rated as more engaged on RDIs for teacher ratings, independent measures, photo ratings, and a composite index of redirections STRESS: NA Other: NA Covariates: NA Study Population: N = 20 (Male = NA; Female = NA); Middle Childhood (9-10 Years, M = 9.5); United States
Largo-Wright et al. (2018)	Longitudinal; Mixed Effects Model	ATTENTION: No significant findings STRESS: NA Other: Children in green settings required fewer redirections compared to those in non-green; happiness and wellbeing unrelated to green setting Covariates: NA Study Population: N = 37 (Male = 20; Female = 17); Early Childhood (5-6 Years, M = 5.5); United States
Larson et al. (2018)	Cross-sectional; Logistic Regression	ATTENTION: NA STRESS: % zip code level canopy coverage predicts greater self-reported Anxiety problems in children with Autism compared to Typical Children and other Children with Special Healthcare Needs Other: NA

Study	Design	Synopsis
		Covariates: Age, Gender, Race/Ethnicity, SES, Maternal Education, % Impervious Space, Diagnostic Group, Autism Severity, Depression Severity, Conduct Problem Severity, IQ Problem Severity, Learning Problems Severity, ADHD Severity Study Population: N = 70,817 (Male = NR; Female = NR); Early Childhood to Adolescence (6-17 Years, M = 11.5); United States
Markevych et al. (2018)	Cross-sectional; Relative Risk Models, Multi-level	ATTENTION: Greenness associated with decreased risk of ICD-ADHD diagnosis STRESS: NA Other: NA Covariates: NO2 levels, Number psychiatrists in region, Gender, Year of birth, Home address Study Population: N = 66,823 (Male = 34,100; Female = 32,723; ADHD = 2,044); Middle Childhood to Adolescence (10-14 Years, M = 12.0); Germany
Mennis et al. (2018)	Longitudinal; Generalized Estimating Equations	ATTENTION: NA STRESS: Green space X Setting interaction showing impact of green space predicts RDI Stress for children in non-home settings Other: NA Covariates: Age, Race, Emotion Dysregulation, Setting (Home; Not Home), Season, Neighborhood Disadvantage Study Population: N = 179 (Male = 76; Female = 103); Adolescence (13-14 Years, M = 13.5); United States
Mygind et al. (2018)	Quasi-experimental (Within, Attention/Stress Manipulation): (a) Green environment, (b) Classroom; Generalized Estimating Equations	ATTENTION: No significant findings STRESS: Tonic Vagal Tone higher in green setting Other: NA Covariates: Gender, Age, Condition Sequence Study Population: N = 47 (Male = 29; Female = 18; All Condition = 20 per); Middle Childhood (10-12 Years, M = 10.9); Denmark
Van Aart et al. (2018)	Cross-sectional with Linear regression; Longitudinal with Linear Mixed Model	ATTENTION: Agricultural green areas associated with decreased Strengths and Difficulties Questionnaire ADHD scores STRESS: Proximity to green areas associated with decreased reported Anxiety Other: Natural and forested green areas associated with decreased reported RDI - Sadness and Total Negative Emotions, and increased Happiness; Longitudinal models show greater increases in Happiness for those living in Natural and forested greener areas

Study	Design	Synopsis
		Covariates: Gender, Age, Agricultural area, Industrial area, Residential Area, Distance to major road, Traffic Density, Noise Pollution, Black Carbon, Particulate Matter Study Population: N = 224 (Male = 113; Female = 111); Middle Childhood to Adolescence (8.7-13.7 Years, M = 11.2); Belgium
vanDijk-Wesselius et al. (2018)	Quasi-experimental (Within): (a) Paved schoolyards and (b) Greened schoolyards; Pre-post and follow-up; Multi Level Modeling	ATTENTION: Student Digit Letter Substitution Test and Sky Search Task scores increased in greened schools compared to control STRESS: NA Other: Student Perceived Naturalness of and appreciation for schoolyards increased in greened schools; gender X time interaction showed that Moderate Vigorous Physical Activity increased for girls in green condition from pre to post, but not follow up; grade X time interaction showing that Strengths and Difficulties Questionnaire Prosocial scores increased pre to post for 4th and 5th graders in intervention, but not 6th graders Covariates: Gender, Grade Study Population: N = 706 (Male = 355; Female = 351); Early to Middle Childhood (8-13 Years, M = 8.6); Belgium
Wallner et al. (2018)	Quasi-experimental (Within): (a) Small urban park, (b) Large urban park, (c) Forest setting; ANOVAs	ATTENTION: D2 scores higher following forest setting compared to other settings STRESS: Reduced decline in reported Nitsch Tension scores following exposure to green forest setting compared to other settings Other: Nitsch Recuperation, Mood, Action, Readiness, Exertion Readiness, and Alertness metrics were better following exposure of green forest settings compared to other settings Covariates: Study Population: N = 60 (Male = 30; Female = 30); Early Childhood to Adolescence (6-18 Years; M = 12); Austria

Notes:

ADHD = Attention Deficit Hyperactivity Disorder

M = Mean

Mdn = median, estimated from age ranges if mean not provided in study

NA = Not Applicable

NR = Not Reported

SES = Socio-economic Status