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Review article

Landscapes of becoming social: A systematic review of evidence for associations and pathways between interactions with nature and socioemotional development in children

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ABSTRACT

Background: Existing research indicates that spending time in nature is associated with diverse aspects of children's health and wellbeing. Although fundamental to later life chances and health, no systematic reviews, to our knowledge, have focused specifically on the effects of interaction with nature on socioemotional functioning in childhood.
Objectives: Amongst children, what is the consistency of associations between the availability of or spending time in nature on socioemotional function and development? Furthermore, which child behaviours and states independently associate with socioemotional function and availability of or spending time in nature, and what is the consistency of associations between these behaviours and states and contact with nature?
Data sources: Embase, Environment Complete, MEDLINE, and APA PsycINFO. Eligible studies were backward and forward snowball-searched.
Study eligibility criteria: Studies investigating effects of, or associations between, availability of or interaction with nature on socioemotional or proximal outcomes in children under the age of 12 years were included in this review.
Study appraisal and synthesis methods: The internal validity of studies investigating socioemotional outcomes were based on assessments of elements of study design, conduct, and reporting to identify potential issues related to confounding or other biases. The number of analyses indicating positive, negative, and non-significant associations between availability or interaction with green space and the outcomes were summed.
Results: A total of 223 eligible full-texts, of which 43 pertained to socioemotional outcomes and 180 to proximal outcomes, met eligibility criteria. Positive associations between availability of and spending time in green space were found with children's intra- and interpersonal socioemotional function and development. Proportions of positive findings ranged from 13.9% to 55% across experimental and observational research, exposures, populations, and contexts. Modifying and mediating factors were identified.
We found consistent evidence for improved aspects of cognition and, for children over six years, reduced risk of obesity and overweight in association with green space; consistent links between movement behaviours in the experimental, but not observational research; tentative trends suggesting associations with play, motor skills,

Abbreviations: BW, birth weight; LPA, low-intensity physical activity; MVPA, moderate-to-vigorous physical activity; PA, physical activity; PB, preterm birth; SGA, small for gestational age; VPA, vigorous physical activity.

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language, screen time, and communication skills; little evidence for positive associations between green space and mood, physical wellbeing, and stress; some evidence for associations with healthy birth outcomes, and little evidence for direct associations between availability of green space and asthma and allergy prevalence, however, mediation via, for example, air pollution was likely.
Limitations: We identified few studies without either probable or severe risk of bias in at least one item. Improved study quality may therefore result in different results. Restricting analyses to include only studies considered at low risk of bias indicated similar or slightly lower proportions of positive findings. Risk of bias in proximal outcomes was not assessed.
Conclusions: The empirical evidence for benefits of availability of and interaction green space for child socio-emotional function and development must currently be considered limited. A number of proximal indicators were identified.
Systematic review registration number. PROSPERO ID: CRD42019135016.

1. Introduction

Health inequality is increasingly attributed to social determinants such as poverty, social exclusion, or sub-optimal early childhood development (Marmot, 2005; Moore et al., 2015). Early childhood physical, socioemotional, and cognitive development, each equally important and interdependent, strongly influence wellbeing, obesity, stunting, mental health, and heart disease throughout life (Irwin et al., 2007). Optimising developmental opportunities is thus of paramount importance from a humanistic as well as societal and economic perspective (Hanson and Gluckman, 2011; Heckman, 2008).

Shonkoff and Phillips (2000) describe socioemotional development as the emerging capacity to recognise one's own feelings, and the capacity to manage and adapt these as socially appropriate. A child's ability to identify and regulate emotions and behaviours in early development is thus interconnected with the child's relations with others, and is a core competency for adaptive behaviours throughout life (Shonkoff and Phillips, 2000). While children are born ready to "learn, grow, and 'become'", (Shonkoff and Phillips, 2000, p. 32) with an attentional predisposition towards social stimuli and social learning, the risk and protective factors influencing the course of development may be modified by effective interventions in early childhood.

Child development is undoubtedly heavily influenced by both individual and social factors, such as genetics or warm and affectionate caregiving (Shonkoff et al., 2009). However, the natural environment is increasingly seen as a health determinant that in its absence disproportionately negatively affects poorer people living in poor housing (World Health Organization & WHO Commission on Social Determinants of Health, 2012). Public natural environments hold promise as a vehicle of change being widely accessible, modifiable, lasting, and inexpensive once implemented (Hordyk et al., 2015; Newman et al., 2015). Small benefits for the individual, when applied to large populations, can provide considerable impacts at a societal level (Rose, 2001).

Ethnographic, theory-developing work has identified a number of mechanisms through which contact with nature might influence whole child development (for a review, see Chawla, 2015). Contact with nature is theorised to support children's realisation of their capabilities through, for example, the provision of opportunities to engage in cooperative, imaginative, and pretend play (Chawla, 2015), while fostering reasoning, communication, and interactional skills (e.g. turn-taking, conflict resolution, social cognition, and self-regulation). Additionally, self-paced or caregiver-guided challenges and so-called 'risky play' afforded by natural environments (Fjørtoft, 2004; Sandseter and Kennair, 2011) are thought to nurture a sense of bodily mastery, emotion understanding, and management, as well as a sense of accomplishment and agency. Natural loose parts (e.g. rocks, branches, and sand) are theorised to encourage constructive play and invite children to engage with and modulate their environment (e.g. building forts or dens, inspiring confidence that they can control their own surroundings). Finally, quiet retreats and 'green refuge' allows for emotional restoration and management, perhaps particularly important for shy or introverted children (Chawla, 2015).

The potential of natural environments is supported by a growing number of literature reviews that accumulate and discuss the evidence for the developmental and health benefits of contact with nature on children and adolescents (Faber Taylor and Kuo, 2006; Gill, 2014; Holland et al., 2018; McCurdy et al., 2010; Mygind et al., 2019a; Tillmann et al., 2018b). Childhood exposure to nature has also been associated with adult socioemotional function and mental health; for example, through lowered risk of depressive symptoms (Bezold et al., 2018) and psychiatric disorders during adulthood while controlling for socioeconomic factors (Engemann et al., 2019). These findings suggest a potential cause-and-effect relationship yet may be subject to sources of unmeasured confoundment.

Although the both plausible and appealing narrative often told suggests that the benefits of nature on child development are consistent, important, and widely replicated, issues necessitating scepticism remain. In particular, the quality of the evidence is mixed and it seems that the consistency of the findings are less convincing when addressed at an outcome level across studies (Mygind et al., 2019a; Tillmann et al., 2018b).

In this review, we synthesise and critically assess the research pertaining to the potential for interaction with nature to enhance children's socioemotional function and development. We focus specifically on socioemotional function and development, as this may be a particularly relevant outcome in relation to nature exposure (Mygind et al., 2019a; Tillmann et al., 2018b) that, to our knowledge, has not been subjected to rigorous and detailed assessment. In addition, there is, to our knowledge, no evidence-based mechanistic model to explain the presumed effects of interaction with nature and socioemotional development. Under predetermined conditions, we include proximal measures of socioemotional development (e.g. child states or behaviours that facilitate socioemotional growth) to expose the child-relevant pathways through which interaction with nature might influence socioemotional development. On the basis of these pathways, we propose an evidence-based mechanistic mosaic connecting interaction with nature and socioemotional development.

This paper thus encompasses a systematic review of the existing experimental and observational evidence for effects of, and associations between, contact with nature and childhood (from conception to age 12) socioemotional development. The primary objective is to investigate:

P: Among humans under the age of 12 years, what is the association
BETWEEN EITHER
I: nature-based interventions versus
C_I; no-treatment or treatment-as-usual control conditions
OR
E: exposure to natural environments versus
C_E: comparatively lower or no exposure to natural environments
ON
O: socioemotional function or development.

Exposures and interventions were expected to enhance socioemotional functioning and development and the primary objective was in this regard confirmatory. However, a multitude of exposure and outcome measures are used in the existing research, as well as analytical approaches and exposure levels to examine associations between these, as common methodologies and gold-standards for operationalisation and measurement do not currently exist. Furthermore, there is currently no consensus in the research on which to base expectations regarding shape and distribution of potential relationships. Individual exposures and outcomes were therefore not pre-defined, nor were hypotheses at the level of individual exposures or interventions and outcomes. In this respect, the primary objective was exploratory.

Secondarily, this paper aims to map so-called proximal outcomes that can be incorporated into a larger mechanistic model, a mosaic, that is used to 1) provide a coherent framework for understanding the interaction between nature interaction and children's socioemotional function and development, 2) clarify empirical support for presupposed mechanisms, and 3) identify pathways that call for further research. Using evidence mapping (Sutton et al., 2019), research investigating the same population (P), exposure/intervention (E/I), and comparator (C), stated as part of the primary objective, was explored. Proximal socioemotional development outcomes (P-SDO's) were defined as behaviours and states that both associated with or were improved through contact with nature and associated with or improved socioemotional development outcomes (SDO). The mapping of these P-SDO's was exploratory. Databases including identified original studies and extracted information for the individual studies, as well as a codebook, are available in Appendix A and B and via the Open Science Framework (OSF) (https://osf.io/fs5m7/?view_only=b833ff48f2314d43b12c3af7a1ea1be8).

2. Methods

2.1. Protocol and registration

The review protocol can be accessed online on PROSPERO (https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=135016) under the following registration number; CRD42019135016. The PRISMA report for systematic reviews is enclosed in Appendix C.

2.2. Eligibility criteria

The review included peer-reviewed publications in English language. Included studies used experimental or observational designs, were based on quantitative analyses, involved participants under the age of 12, and investigated effects of, or associations between, access to, exposure to, or interaction with nature on socioemotional or proximal outcomes. Measures and instruments were not predefined.

Exposure to nature included direct engagement with, passive exposure to, and access to natural environments. Inspired by the conceptualisation made by Hartig et al. (2014, p. 208), nature here referred to "physical features and processes of nonhuman origin that people ordinarily can perceive, including the 'living nature' of flora and fauna, together with still and running water, and the landscapes that comprise these and show the influence of geological processes." In this review, we focused on typical conditions for interaction with natural environments; that is, not extreme weather conditions such as droughts, hurricanes, or floods. These types of events can be expected to be connected to great trauma and stress, with consequences for children's socioemotional function, but they are outside the scope of this review. We therefore excluded studies investigating effects of pet companionship and animal-assisted therapy when these were removed from natural environments. Some exposures, such as outdoor time, or features, such as loose parts (e.g. rocks, branches, or sand), are in the literature automatically connected or thought of as natural. Loose parts are sometimes, but not necessarily, natural features. Unless specified further than loose parts, such studies were excluded. Likewise, studies investigating effects of outdoor time without specifying where such time was spent were excluded.

Inter- and intrapersonal socioemotional function and development were included as primary outcomes. Interpersonal categories involved establishment and maintenance of positive relationships (e.g. peer relationships and friendships), adaptive behaviours (i.e. prosocial behaviour, cooperative behaviours, and conduct problems), and social competence (e.g. social cognition and empathy). Intrapersonal features were emotion management and expression (e.g. emotional wellbeing, anxiety, and depression), behavioural inhibition (e.g. inattention symptoms, hyperactivity, and self-control), and thoughts of self (e.g. self-esteem and -perception).

P-SDO's were identified through a preceding scoping review (the approach is described in Section 2.4) and included as secondary outcomes. P-SDO's were defined as behaviours and states that both associated with or were improved through contact with nature and associated with or improved SDO's. P-SDO's met the following criteria: 1) the P-SDO had been theorised in the identified literature to be associated with both nature and SDO, respectively, such that contact with nature would have effects on P-SDO which would then promote SDO; 2) the link between nature interaction and the P-SDO had been demonstrated empirically, with controls for socioeconomic status; and 3) the P-SDO–SDO link had been demonstrated empirically independent of its relationship to nature. Thus, for example, the link between obesity, social participation, and emotional dysregulation was demonstrated by Pizzi and Vroman (2013). Outcomes identified during the scoping review were supplemented by additional P-SDO's found through the database search.

2.3. Information sources

The following databases were selected through consultation with the Deakin University School of Psychology Liaison Librarian, and searched: Embase (via embase.com), Environment Complete, MEDLINE, and APA PsycINFO (via EBSCOhost). All eligible studies were backward snowball-searched manually, and forward snowball-searched using the Web of Science citation tracking feature.

2.4. Search

The scoping review approach was based on a snowball method using the seminal publication by Hartig et al. (2014) as a so-called seed publication. The seed paper is a review of reviews exploring benefits of interaction with natural environments on mental, physical, and social health outcomes. The publication had been cited more than 460 times on the 21st of May 2019, when the search was commenced, making it one of the most cited articles in the field.

From the seed paper, 11 seed reviews (Annerstedt and Währborg, 2011; Bell et al., 2008; Bowler et al., 2010; Bratman et al., 2012; Ding et al., 2011; Dunton et al., 2009; Konijnendijk et al., 2013; McCurdy et al., 2010; Muñoz, 2009), covering diverse aspects of health, were identified through backwards, manual snowballing. The seed publication and the seed reviews were forwards snowball-searched using the Web of Science citation tool. Identified papers were subsequently backward and forward snowball-searched until no additional papers were found on May 30th. In this process, potential P-SDO's were extracted and continuously submitted to eligibility testing. P-SDO's that did not fulfil the first criteria (that is, studies including a proposition that the P-SDO would be associated with SDO), were included on a probationary level in case subsequently identified papers suggested a linkage. Likewise, papers in which no test or control for socioeconomic confounding had been performed, relating to the third P-SDO criteria, were provisionally included.

The database search string included synonyms for natural environments in conjunction with synonyms for SDO's and P-SDO's, as well as words relating to child populations. The synonyms were informed by words used in the literature that were identified in the scoping review procedure. The full search string was evaluated by the Liaison Librarian. The generic search string was supplemented with subject headings specific to the individual databases. English language and peer review limiters were used in the three EBSCOhost supported databases, and English language and human research limiters were used in Embase. The full search strings are enclosed in Appendix D. Database searches were finalised in the second week of June 2019. Eligible studies were subsequently backward snowballed manually and forward snowballed using the Web of Science citation tracking feature. Snowballing searches concluded in the third week of September 2019.

2.5. Study selection

References from the database search were entered into the Rayyan online platform (Ouzzani et al., 2016). Study selection was divided into two phases: 1) title and abstract screening and 2) full text eligibility assessment. Both phases were performed by two investigators using a standardised guide for the study selection process. The study selection guide is included in Appendix E. An interrater agreement of 95% (27 conflicting assessments out of 463 full-text screened) was achieved during the full text eligibility phase. Discrepancies were solved through discussion.

2.6. Data collection process

Two different data collection procedures were applied for the primary outcomes (i.e. the SDO's) and secondary outcomes (i.e. the P-SDO's).

For the SDO's, two researchers extracted data from all studies. Discrepancies were solved through discussion. For the P-SDO's, one researcher extracted data. This differs from the original plan as registered on PROSPERO, where 10% of all studies, including SDO's and P-SDO's, were to be submitted to data extraction. This change was made to enhance the validity and rigour of assessments of all the studies including SDO's, while accommodating resource and time restraints within the author group.

2.7. Data items

Data items included in the SDO data collection included characteristics of the studies (i.e. methods, participants, intervention and control groups, and outcomes), outcome specific information, data and analysis, and other information. Data extraction sheets were adapted from the Cochrane form for experimental research, including RCT's and non-RCT's, and observational research. Two different sheets were used for experimental and observational studies, included in Appendix F and G, respectively.

Data items included in the P-SDO data collection included 1) Basic article information (author, publication date), 2) Sample (age under or over six), 3) Design (experimental or observational), 4) Type of nature contact (accessibility, passive exposure, or interaction), 5) Context of nature contact (home, home neighbourhood, institution, institution neighbourhood, treatment, or unspecified), 6) Type of exposure (short description), 7) P-SDO outcome, 8) Results (non-significant, positive, or negative), and 9) Remarks.

2.8. Data management

SDO's were aggregated to six pre-defined domains (i.e. intrapersonal SDO's: 1) emotion management and expression, 2) behavioural inhibition, or 3) thoughts of self, and interpersonal SDO's: 4) establishment and maintenance of positive relationships, 5) adaptive behaviours, or 6) social cognition, empathy, and social competence). We also included a compound category for SDO's that addressed several of these domains at a time, as well as a child psychopathology category for assessments of neuro-developmental disorders, such as autism spectrum disorder (ASD) and Attention-Deficit/Hyperactivity disorder (ADHD). These domains were used to organise the result presentation in the following sections. Please see Appendix H for specification of the measurements included under the individual socioemotional domains.

P-SDO's were grouped within 13P-SDO domains: cognition, play, movement behaviours, screen time, healthy weight, stress, mood, physical wellbeing, motor skills, language and communication skills, birth outcomes, allergy, and asthma. These domains were derived from the existing literature in an exploratory way to group similar behaviours and states and are used to systematise the result presentation in the following sections. We appreciate that other categorisations could have been made and invite readers to use the appended database to create categories that are meaningful to their purposes. Appendix I lists the outcomes and their placement under the individual domains.

A few distinguishing notes are necessary concerning P-SDO's around which inconsistent terminology was used. In particular, the literature pertaining to cognitive outcomes uses a vast number of terms with varying conceptual consistency and we therefore superimposed an existing classification system (Stevenson et al., 2018). We distinguished between attention (termed 'attentional control' by Stevenson et al., 2018), working memory, inhibitory control (termed 'impulse control' by Stevenson et al.), cognitive flexibility, and processing speed. We also included global measures of cognition for broader assessments of cognitive ability and intelligence. However, while the tasks were categorised according to the domain which it is thought to predominantly reflect, none of the tasks were thought to provide 'pure' measures of the cognitive domains in which they are categorised. We were unable to categorise one task under a suitable cognitive domain (Carrus et al., 2012) and the analysis was not included the cognitive domain summaries. Appendix J lists the outcomes and their placement under the individual cognitive domains.

Furthermore, we distinguished between self-reported measures of stress, and acute (e.g. salivary cortisol and heart rate variability) and cumulative (e.g. hair cortisol) psychophysiological stress response measures. Kalashnikova et al. (2016) used the so-called Lüscher test to reflect non-productive psychological stress. Although this approach may have some legitimacy, the construct validity as a measure of stress is questionable. Indeed, the test has seen widespread criticism (e.g. for strong indications of the Barnum effect; Holmes et al., 1986). Therefore, the analysis was not included the stress response summaries.

All data was entered manually into domain-specific databases which are available via the OSF and are appended this publication (Appendix A). A supplementary codebook listing variable names, variable labels, and variable values was also developed and is accessible via the OSF and Appendix B.

2.9. Risk of bias in individual studies

Two researchers performed risk of bias assessments for all SDO studies. Discrepancies were resolved through discussion. P-SDO studies were not subjected to risk of bias assessment. This diverges from the original plan described on PROSPERO. As described above, this change was made to enhance the validity and rigour of assessments of all the studies including SDO's while accommodating resource and time restraints within the author group. The NTP-OHAT Risk of Bias Assessment Tool (National Institute of Environmental Health Sciences, 2015) was used. The tool presents a unified approach to evaluating risk of bias (i.e. selection, confounding, performance, attrition/exclusion, detection, and selective reporting) across a range of study types, both observational and experimental (randomised and non-randomised). Risk of bias assessments are included in Appendix K.

2.10. Summary measures and synthesis of results

A combination of quantitative and narrative synthesis of the results was conducted. We applied a vote-count approach to provide an indication of the consistency of the associations within distinct outcome domains. This approach was chosen because the study designs, interventions and exposures, and types of data, were diverse to the extent that meta-analyses were not feasible (Campbell et al., 2020). For both SDO's and P-SDO's, the evidence was synthesised by summing the number of studies indicating positive, negative, and non-significant associations between availability or interaction with green space and the outcomes. A 5% significance level was applied. Since some studies used several indicators to measure aspects of the same construct (e.g. Markevych et al., 2014a; Mygind et al., 2018; Reuben et al., 2019), these were counted as individual analyses and were included in sum scores. As such, if two different measures were used to indicate the same aspect of socioemotional function or development, these two measures could either converge or diverge, which would then be interpreted as consistency or inconsistency, respectively. A similar logic was applied to studies using more than one nature exposure measure. Counts were generated in R version 3.6.3 (2020-02-29) and summed manually (please see Appendix L for example scripts).

These vote-count scores were further explored by comparing proportions across population, intervention/exposure, and comparator specific groupings; type of design (i.e. experimental or observational), urbanicity (i.e. urban residency or otherwise), age group (i.e. under or over age six), types of nature contact (i.e. accessibility, exposure, or interaction), context of nature interaction (i.e. at or around the home, at or around the educational institution, or treatment), and proximity of accessibility type nature exposures (i.e. immediate $\leq$100 m from home or institution, intermediate $>$100 m & $<$500 m, neighbourhood $\geq$500 m, other). These groupings were selected as they have previously been identified as possible interacting factors, or sources of heterogeneity, in the relationship between contact with nature and SDO's and P-SDO's (Mygind et al., 2019a). However, the direction of which these factors would interact with associations is currently speculative and was therefore not supported by pre-defined hypotheses.

Every SDO and P-SDO domain was subjected to the same comparative analyses when possible, that is, when the absolute number of grouping events was sufficiently large to make meaningful comparisons. The usefulness of tabular representations of the findings across all these groupings was reduced by limited absolute numbers of analyses per grouping event, e.g. cases of purely urban samples or interaction type contact with nature. Instead, we present this information in the text, when relevant. The findings across the most consistently accessible groupings, i.e. experimental or observational type of design and context of nature interaction, is presented in tabular form. These tables also include results specific to the best available evidence, that is, analyses with few risk of bias concerns. These are presented when more than ten analyses were found under the individual grouping. SDO results by age group are included in Appendix M.

Results from individual studies using stratification for, e.g. child sex, maternal education, or race, was described narratively to supplement the vote-count syntheses.

Finally, a figurative illustration of mechanisms linking interactions with nature and socioemotional development, through the identified P-SDO's, was made.

2.11. Risk of bias across studies

To illustrate risk of bias across the body of evidence, we aggregated individual risk of bias items. Publication bias was indicated by *p*-curve analysis if there was a sufficient amount of studies reporting exact *p*-values.

3. Results

3.1. Study selection

The initial scoping review and database searches resulted in 3266 unique items that were subjected to title and abstract screening (see Fig. 1 for flow diagram). After exclusion of 2866 items that were outside the scope of the review due to clear reporting of non-relevant analytical methods, outcomes, exposures or interventions, and/or populations, 400 articles were full-text assessed. Amongst these, 64 were excluded due to investigating a non-relevant intervention or exposure, while 40 did not include SDO or P-SDO, 36 encompassed wrong populations, 32 were not accessible as full, peer-reviewed papers (e.g. conference abstracts), 25 did not include quantitative analyses, 19 presented no empirical results, 12 were before-and-after studies without a control group, six presented unclear interventions, five were double publications, and two were published in languages other than English. Upon backwards and forwards snowball searching the remaining studies, we identified a total of 222 eligible full-texts, of which 43 pertained to SDO and 180 to P-SDO.

3.2. Study characteristics

We identified 26 observational (including 68 exposures) and 17 experimental studies of which 22 studies stemmed from Europe (i.e. Belgium: 1, Denmark: 3, Germany: 3, Italy: 3, Lithuania: 1, the Netherlands: 2, Spain: 1, Sweden: 2, and UK: 6), 12 from North America (i.e. Canada: 1 and the USA: 11), four from Australasia (i.e. Australia: 3 and New Zealand: 1), two from South Korea and one from Israel and Iran, respectively (please refer to Table 1 for study characteristics). Table 2.

Most analyses included children over the age of six (71.1%, $n = 83$). Analyses from experimental studies predominantly investigated interventions set in educational or early childcare settings (76.5%, $n = 17$), whereas observational studies were dominated by investigations of residential greenery (70.2%, $n = 68$), and more infrequently, use of green space without location specification (6.3%). Availability of residential greenery was operationalised as the proportion of vegetation within a specified boundary (e.g. the Normalised Difference in Vegetation Index, Rhew et al. (2011)), distance to nearest green space, presence or absence of green space within specified boundary, and existing municipal or governmental classifications of, e.g. parkland, forest, or grassland.

Outcomes varied greatly with representation across inter- and intrapersonal categories. We present these in Section 3.4.

3.3. Risk of bias within studies

Tables 3 and 4 include risk of bias assessments for observational and experimental studies, respectively. In instances where more than one intervention or exposure and/or outcome measure was/were included in the same study, and was evaluated to involve differential risk of bias, both ratings were included (e.g. Amoly et al., 2014).

3.4. Results of individual studies

Findings across socioemotional domains are summarised in Table 5. In the following, analyses refer to non-stratified analyses unless otherwise specified.

3.4.1. Establishment and maintenance of positive relationships

3.4.1.1. Characteristics of analyses based on generic measures. Seven observational and four experimental studies were identified. The most commonly used measurement tool ($n = 9$ studies) was the parent-reported Strengths and Difficulties Questionnaire (SDQ) (Goodman and Goodman, 2009) indexing peer relationship problems (please, see Appendix H for the other measures). Most of the analyses from observational studies investigated how residential greenery associated with the children's generic ability to establish and maintain positive

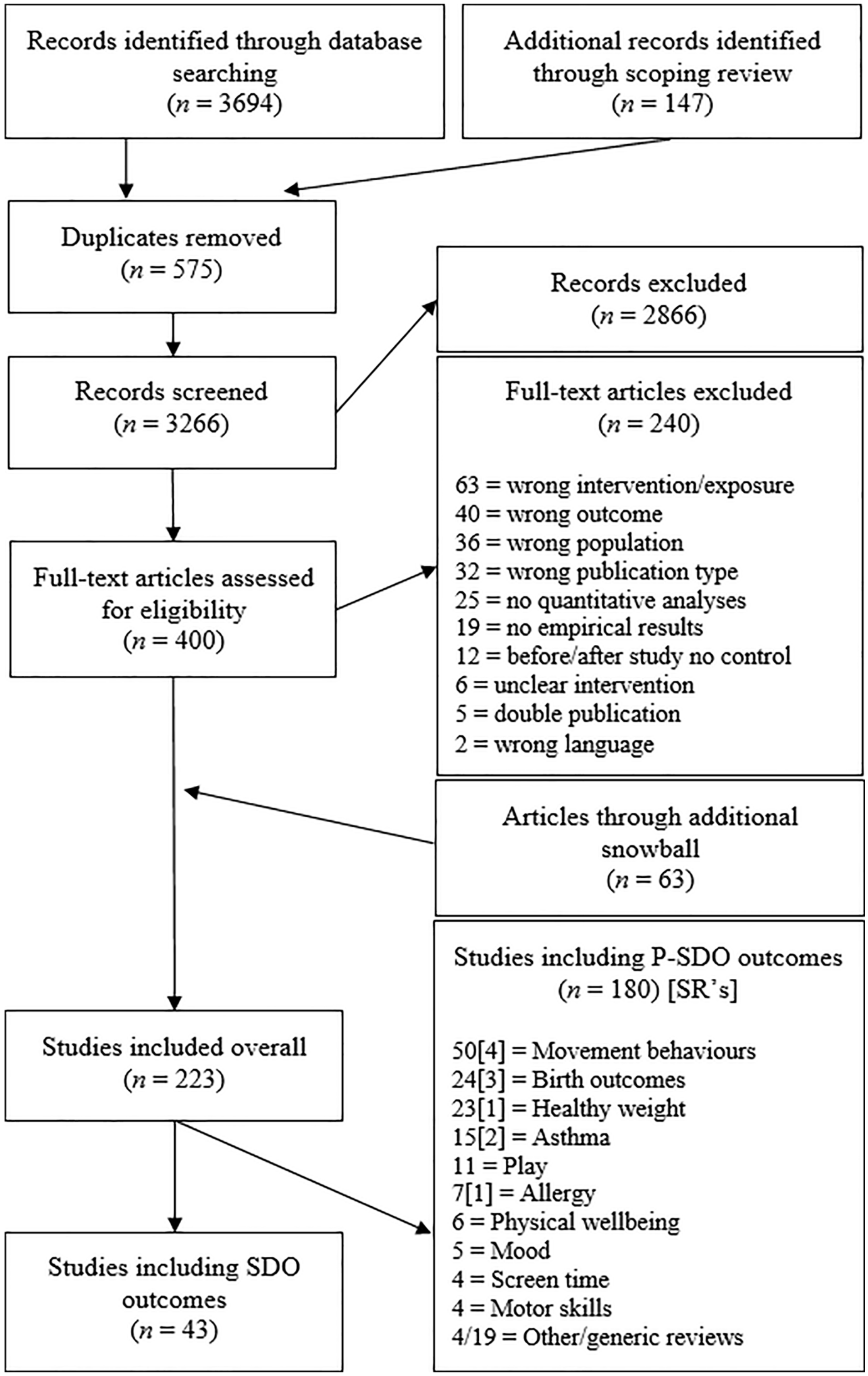

Fig. 1. Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) flow diagram summarising the systematic literature search, inclusions and exclusions. Note: [SR's] refer to the number of reviews under each P-SDO category.

relationships (74.2%, $n = 31$). Sample sizes ranged from 224 to 6384. Studies had few or some risk of bias concerns. Five analyses from the experimental studies were all based in a school-setting investigating education outside the classroom (Bølling et al., 2019a; Gustafsson, 2012; Mygind, 2009) or school ground greening (van Dijk-Wesselius et al., 2018). Sample sizes ranged from 19 to 631. Studies involved some or serious risk of bias. Most of the analyses encompassed children over the age of six (90.8%, $n = 36$).

3.4.1.2. Synthesis. The ability to establish and maintain positive relationships associated positively with availability of and spending time in nature in 19.4% ($n = 36$) of the analyses across observational and experimental studies. However, the proportion of positive findings from analyses including only urban samples was slightly higher (27.3%, $n = 33$). Due to the small absolute number of positive findings, it was not possible to identify further potentially stratifying factors.

Table 1
Study characteristics, observational studies.

ID	Study characteristics	Exposure studied (unit)	Exposure measurement (*measured confounding variables*)	Outcome assessment (tool)
(Amoly et al., 2014)	Cross-sectional, Urban area residents, [7–10] years, 50.7% ♂, Spain; $n = 2111$	a) Residential vegetation 100, 250 and 500 m; School vegetation 100 m; Sum residential and school vegetation (IQR) b) Green space within 300 m from home (yes/no) c) Hours play in any green space (IQR), Beach attendance (IQR)	a) NDVI (30*30) b) Ecological Map of Barcelona c) Parent-report, N.R. *Child; school, sex, ethnicity, preterm birth, breastfeeding, exposure to environmental tobacco smoke. Parent; maternal smoking during pregnancy, educational achievement, employment status, marital status. Neighbourhood; SES.*	Total difficulties; Emotional symptoms; Conduct problems; Hyperactivity/Inattention; Peer relationship problems; Prosocial Behaviour (SDQ) ADHD symptoms; Inattention symptoms; Hyperactivity-impulsivity symptoms (ADHD/DSM-IV)
(Balseviciene et al., 2014)	Cross-sectional, Urban area residents, FP7 PHENOTYPE cohort, [4–6] years, 49,3% ♂, Lithuania; $n = 1172$[a] & 296[b]	a) Residential vegetation 300 m (scale) b) Distance from home to nearest park (scale)	a) NDVI (30*30) b) Municipal land cover data *Unclear beyond stratification for maternal educational attainment.*	Total difficulties; Emotional symptoms; Conduct problems; Hyperactivity/Inattention; Peer relationship problems; Prosocial Behaviour (SDQ)
(Carrus et al., 2012)	Within-subjects, no cross-over, Children in private childcare centres, [1.5–3] years, sex N.R., Italy; $n = 16$	Play in centre exterior green space vs. interior space	Observation, Developed by authors *None.*	Small group play; Self-organised play; Educator interventions; Boredom feelings; Educator dispute resolution; Crying episodes; Comfort capacity (observation, tool developed by authors)
(Carrus et al., 2015)	Within-subjects, no cross-over, Children in childcare centres, [1.5–3] years, sex N.R., Italy; $n = 39$	Play in centre exterior green space vs. interior space	Observation, Developed by authors *None.*	Positive affective state; Negative affective state; Positive social interaction; Negative social interaction; Cooperative activities; Educators interventions (observation, tool developed by authors)
(Christian et al., 2017)	Cross-sectional, Children in first year of school, $\bar{x} = 5.3$ (SD: N.R.) years, 51.8% ♂, Australia; $n = 23{,}395/143$ spatial units	Distance from home to nearest pocket park (per 100 m increase); Distance to nearest nature/conservation area (per 100 m increase)	Public Open Space (POS) Tool classification, distances calculated in GIS *Spatial unit-level; child sex, Aboriginal or Torres Strait Islander, siblings, single parent family, parent > 24 years, parental education > secondary school, family income < $3000/fortnight, moved house in last 12 months, Index of Education and Occupation.*	Emotional maturity; Social competence (AEDC)
(Donovan et al., 2019)	Cross-sectional, All children born in New Zealand in 1998, ~18, 51.5% ♂, New Zealand; $n = 49{,}956$/nr. spatial units N.R.	Residential vegetation within spatial unit (scale, quartiles, a) ref; lowest, b) ref; highest)	NDVI (30*30) *Child; ethnicity, sex, birth order, antibiotic use, low birthweight. Maternal; smoking status, educational level, age at parturition. Stratification by child sex, ethnicity, rural/urban residency, maternal education, neighbourhood deprivation.*	Incidence of ADHD (ICD-10-GM F90 or two or more prescriptions for ADHD medicine)
(Feng and Astell-Burt, 2017)	Cohort, Population unspecified, The Longitudinal Study of Australian Children (LSAC), [4–5] years, 50.9% ♂, Australia; $n = 4{,}968$/nr. spatial units N.R.	Proportion residential green, public/private open space within spatial unit (range, a) 6–20%, b) 21–41%, c) ≥ 41%, ref; 0–5%)	Australian Bureau of Statistics Parkland indicator *Child; sex, indigenous status, Spatial unit-level; deprivation index, remoteness index.*	Total difficulties; Internalising behaviours; Externalising behaviours (SDQ)
(Flouri et al., 2014)	Cohort, Urban area residents, the Millennium Cohort Study (MCS), ~3, sex N.R., England; $n = 6384$/nr. spatial units N.R.	Proportion residential green space within spatial unit (scale)	Generalised Land Use Database (2001) *Child; sex, ethnicity, age, two-parent family, family SES disadvantage index, garden-access. Maternal; education < university degree. Neighbourhood; deprivation index.*	Emotional symptoms; Conduct problems; Hyperactivity/Inattention; Peer relationship problems (SDQ)
(Kuo and Faber Taylor, 2004)	Cross-sectional, Children diagnosed with ADHD [5–18] years, 79,31% ♂, USA; $n = 452$	Various leisure activities in unspecified exterior green space vs. a) exterior built space, b) interior built space.	Parent-report, Developed by authors *Child; age, sex, comorbidities, household income, community type, geographical region.*	ADHD symptoms (parent-report, tool developed by authors)
(Lee et al., 2019)	Population unspecified, [7–17] years, 52% ♂, South Korea; $n = 1817$	Residential vegetation 1600 m (scale, tertiles, ref; lowest)	MSAVI (30*30) *Child; age, sex, body mass index (BMI), monthly household income, exposure to second-hand smoke, amount of vigorous physical activity per week, NO2 level and blood lead level (μg/dL).*	Total problems; Internalising behaviour; Anxious/Depressed; Withdrawn/Depressed; Somatic complaints; Externalising behaviour; Rule-breaking behaviour; Aggressive behaviour; Social problems; Affective problems; Anxiety problems; ADHD problems; Oppositional/defiant problems; Conduct problems; Attention problems (CBCL)
(Mårtensson et al., 2009)		High versus low quality of outdoor preschool environment		Inattention; Hyperactivity/impulsivity (ECADDES)

(*continued on next page*)

Table 1 (*continued*)

ID	Study characteristics	Exposure studied (unit)	Exposure measurement (*measured confounding variables*)	Outcome assessment (tool)
	Cross-sectional, Children in metropolitan preschool, [4.5–6.5] years, 57% ♂, Sweden; $n = 198$		The outdoor play environment categories (OPEC) *Maternal; education. Parental; SES.*	
(Madzia et al., 2019)	Cross-sectional, Urban area residents, Cincinnati Childhood Allergy and Air Pollution Study (CCAAPS), ~7 & ~12, 55% & 56% ♂, USA; $n = 562$ & 313	Residential vegetation 200 m, 400 m and 800 m (scale, per 0.1 unit)	NDVI (100*100) *Child; sex, race. Maternal; education. Neighbourhood; deprivation. Household income not included as highly correlated with maternal education.*	Externalising behaviours; Hyperactivity; Attention problems; Aggression; Conduct problems; Internalising problems; Depression; Anxiety; Somatisation (BASC-2)
(Markevych et al., 2014b)	Cross-sectional, Urban area residents, birth cohorts GINIplus and LISAplus, $\bar{x} = 10.1$ (SD: 0.2), 51.4% ♂, Germany; $n = 1932$	a) Residential vegetation 500 m (unclear unit) b) Major green space within 300 and 500 m from home (yes/no); Distance from home to nearest forest (per 500 m increase)	a) NDVI (30*30) b) Bavarian land use dataset (2008) *Child; sex, age, single-parent status at 10-year follow-up, time spent outdoors, time spent in front of a screen. Maternal education, age at childbirth. Stratification by child sex and (for selected outcomes) level of urbanisation.*	Total difficulties; Emotional symptoms; Conduct problems; Hyperactivity/Inattention; Peer relationship problems (SDQ)
(Markevych et al., 2018)	Cohort, Customers of large health insurance provider (AOK PLUS), [10–14], 51% ♂, Germany; $n = 66{,}823/186$ spatial units	Residential vegetation within spatial unit (scale, per 0.1 unit)	NDVI (250*250) *Child; sex, age. Neighbourhood; post-code area, Child psychiatrists in 40 km-radius. PM_{10} and NO_2 not included as highly correlated with exposure.*	Incidence of ADHD (ICD-10-GM F90)
(McCracken et al., 2016)	Cross-sectional, Urban area residents, $\bar{x} = 9.7$ (SD: 0.9), 44.4% ♂, Scotland; $n = 276/46$ spatial units	a) Residential proportion green space within spatial units including 500 m buffer (scale) b) Frequency of use of green space (transformed to scale)	a) Central Scotland Green Network b) N.R., Based on governmental tool *Child; sex, age, siblings, access to garden. Neighbourhood: deprivation index.*	Emotional wellbeing; Self-esteem; Family; Friends (Kid-KINDL)
(McEachan et al., 2018)	Cross-sectional, Urban area residents, Born in Bradford cohort study, $\bar{x} = 4.5$ (SD: 0.4), 50% ♂, Scotland; $n = 2594$	a) Residential vegetation 100, 300 and 500 m (scale, per 0.1 unit) b) Distance from home to nearest major green space (scale)	a) NDVI (30*30) b) Parent-report, N.R. *Child; sex, age. Maternal; age, cohabitation status, education, subjective poverty, household size, deprivation index, smoking, mental health problems. Stratification by child race.*	Total difficulties; Internalising behaviours; Externalising behaviours; Prosocial behaviour (SDQ)
(Richardson et al., 2017)	Cohort, Urban area residents, $\bar{x} =$ 4,85 (SD: 0), 51% ♂, Scotland; $n =$ 2909/ nr. spatial units N.R.	a) Proportion residential vegetation within postcode area (per IQR) b) Proportion park space within postcode area (per IQR) c) Access to private garden (yes/no)	a) Scotland's Greenspace Map (2011) b) Scotland's Greenspace Map (2011) c) Parent-report, N.R. *Child; sex, age, age2, screen time. Household; highest educational attainment, equivalised income, carer's mental health. Neighbourhood; deprivation. Stratification by child sex and household educational attainment.*	Total difficulties; Emotional symptoms; Conduct problems; Hyperactivity/Inattention; Peer relationship problems; Prosocial behaviour (SDQ)
(Scott et al., 2018)	Cross-sectional & longitudinal, Children at risk of educational delay, $\bar{x} = 4.45$ (SD: 0.32), 55.4% ♂, USA; $n = 1551/328$ residential spatial units/50 institutional spatial units	Proportion a) residential (fall and fall-spring) and b) institutional tree canopy within spatial unit (per 10% increase)	N.R., Based on existing land cover database *Child; sex, age, ethnicity, institutional attendance. Neighbourhood; median income, violent crime, population density,*	Initiative; Self-regulation; Attachment; Behavioural concerns (DECA-P2)
(Faber Taylor et al., 2001)	Cross-sectional, Children diagnosed with ADD or ADHD, $\bar{x} =$ 9.4 (SD: 1.5), 75% ♂, USA; $n = 96$	Various activities in unspecified exterior green space vs. a) exterior built space, b) interior built space, c) Greenness of child play spaces, d) Naturalness of surroundings, viewed from home (scale)	Parent-report, Developed by authors *None.*	Mean post-activity attentional function; Symptom severity (parent-report, tool developed by authors)
(Faber Taylor et al., 2002)	Cross-sectional, Urban area residents, public housing, [7–12], 53% ♂, USA; $n = 169$	Naturalness of surroundings, viewed from home (scale)	Parent-report, Developed by authors *None beyond stratification by child sex.*	Delayed gratification (Mischel delay of gratification task)
(Tillmann et al., 2018a)	Cross-sectional, Elementary school pupils [8–14], 41.8%[c] & 47.9%[d] ♂, Canada; $n = 467$[c] & 384[d]	a) Proportion of parks within 500 m from home (scale) b) Proportion of water bodies within 500 m from home (scale) c) Residential grass/shrubbery (scale) d) Residential dense vegetation (scale)	a) DMTI Spatial Inc., (Richmond Hill, ON, Canada) park layers b) Natural Resources Canada CanVec c) NDVI (30*30), values of 0.2–0.6 d) NDVI (30*30), values > 0.6 *Child; sex, visible minority, siblings, household income, single-parent household, living in more than one home. Maternal; education, employment. Paternal; education, employment. Stratification by urban/rural.*	Emotional functioning; Social functioning (PedsQL)

(continued on next page)

Table 1 (*continued*)

ID	Study characteristics	Exposure studied (unit)	Exposure measurement (*measured confounding variables*)	Outcome assessment (tool)
(Van Aart et al., 2018)	Cross-sectional, Population unspecified $\bar{x} = 9.7$ [8.7–10.7], 50.9% ♂, Belgium; $n = 224$	Proportion semi-natural and forested area within 100, 300, 500, 1000, 2000, 3000, 400 and 5000 m from home (IQR)	European Coordination of Information on the Environment (CORINE database) land cover 2000 (European Environment Agency). *Child; age, sex. Parental; education.*	Total difficulties; Emotional symptoms; Conduct problems; Hyperactivity/Inattention; Peer relationship problems; Prosocial Behaviour (SDQ)
(Wells, 2000)	Before/after relocation, Low-income families participating in a self-help housing program, [7–12], 52.9% ♂, USA; $n = 17$	Naturalness of surroundings, viewed from home (scale)	Housing Quality – Naturalness Scale, developed by author *None.*	ADHD symptoms (ADDES)
(Wells and Evans, 2003)	Cross-sectional, Children residing in rural areas, $\bar{x} = 9.2$ [6–12], 51% ♂, USA; $n = 337$	Naturalness of surroundings, viewed from home (scale)	Housing Quality – Naturalness Scale, developed by author *Family income.*	Psychological health (RCBQ), Global self-worth (HCS)
(Wu and Jackson, 2017)	Cross-sectional, Public elementary school districts, [5–12], % ♂ N.A., USA; $n = 543$ districts	a) Proportion forest within district; Proportion grassland within district (per 10% increase) b) Proportion tree canopy within district (per 10% increase) c) Percentage near-road trees within district (per 10% increase)	a) National Land Cover Dataset (NLCD) (2011) b) Cartographic Canopy dataset (NLCD) (2011) c) Road network from NavTEQ™ (Chicago, IL), NLCD 2011 Cartographic Canopy dataset *Neighbourhood; economic status (median household income), race (proportion of whitepopulation) and sex (proportion of male population). Stratification by road density.*	Autism prevalence (N.R., LA Times database)
(Zach et al., 2016)	Cross-sectional, Children in preschool, [5–7], 48.1% ♂, Germany; $n = 5117$	Residential availability of public parks or green spaces (binary, yes/no)	Parent-report, N.R. *Child; sex, country of birth. Parental; education, working status. Neighbourhood; traffic load, crowding. Single-parenthood and siblings not found to explain variance in outcome.*	Total difficulties; Hyperactivity/inattention (SDQ)

ADDES; *Attention Deficit Disorder Evaluation Scale*, ADHD/DSM-IV; *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition*, AEDC; *Australian Early Development Census*, BASC-2; *Behavioral Assessment System for Children, Parent Rating Scale, Second Edition*, CBCL; *Child Behavior Checklist*, DECA-P2; *Devereux Early Childhood Assessment Preschool Program, Second Edition*, ECADDES; *The Early Childhood Attention Deficit Disorders Evaluation Scale, School Version*, HCS; Harter Competency Scale, PedsQL; *Pediatric Quality of Life Inventory 4.0*, RCBQ; *Rutter Child Behavior Questionnaire*, SDQ; *Strengths and Difficulties Questionnaire*,
NDVI; *Normalised Difference in Vegetation Index*, MSAVI; *Modified Soil-adjusted Vegetation Index*,
[a] High maternal educational attainment,
[b] low maternal educational attainment,
[c] urban area residents,
[d] rural area residents

3.4.1.3. Stratification. For children aged four to six years, the proportion of natural space within the child's postcode of residence associated with reduced peer problems only for girls, whereas the proportion of park space associated with ameliorated peer problems only for the boys (Richardson et al., 2017). Furthermore, having access to a garden associated with reduced peer relationship problems for boys, but not girls (Richardson et al., 2017). Amongst children around the age of ten, stratification by sex did not reveal differential associations between distance to nearest urban green space and peer relationship problems (Markevych et al., 2014b). Similarly, sex was not found to associate with benefits from education outside the classroom (Bølling et al., 2019a), although some indication was found that children of lower socioeconomic status displayed improvements over and above children of higher socioeconomic status. However, upon stratification, associations with peer relationship problems were no longer significant for any of the groupings. Neither garden access, nor the proportion of natural or park space associated with peer problems amongst children from highly educated homes (Richardson et al., 2017); the proportion of natural space was found to associate with reduced peer problems amongst children from families of low education.

3.4.1.4. Characteristics and synthesis of analyses based on contextual measures. The contextually bound indices of child relationships and interactions with peers and adults were derived from one quasi-experimental (Bølling et al., 2019b) and two observational studies (Carrus et al., 2012, 2015). These studies included 16–490 participants and involved some or serious risk of bias. A number of indices were used within each of these three studies and amongst these, 41.7% ($n = 12$) indicated superiority following education outside the classroom (Bølling et al., 2019b) or during play in childcare exterior green space versus interior space (Carrus et al., 2012, 2015).

3.4.2. Adaptive behaviours

3.4.2.1. Characteristics of analyses. Most analyses from 15 observational studies investigated associations between adaptive, indicated by prosocial, cooperative, independent, and socially appropriate behaviours, and maladaptive behaviours, indicated by conduct problems and aggressive, rule-breaking, oppositional, or other antisocial behaviours, with residential greenery (87.9%, $n = 91$). Sample sizes ranged from 39 to 6384. Studies had both few, some, and serious risk of bias concerns; most studies were rated to involve some risk of bias. The analyses from ten experimental studies investigated interventions set in school settings or as part as treatments ($n = 13$). Sample sizes ranged from 24 to 631. Studies involved some or serious risk of bias, and a single study was considered low risk of bias. The majority of analyses included children

Table 2
Study characteristics, experimental studies.

ID	Study characteristics	Intervention	Control	Outcome assessment
(Ackley and Cole, 1987)	RCT, Cerebral palsy clients, $\bar{x}$ = 13.8 years, 65.9% ♂, USA; n = 44 (i: 22, c: 22)	Horticulture therapy, 10 weeks, 2 sessions weekly	Treatment as usual	Adaptive behaviour (AAMD-ABSCA)
(Block et al., 2012)	Before/after, with control, Government-funded primary school pupils, [8–12], N.R. % ♂, Australia; n = 592 (i: 352, c: 240)	Stephanie Alexander Kitchen Garden program, 12–25 months, 45 min weekly	No intervention	Cooperative behaviours (YLSI)
(Bølling et al., 2019b)	Quasi-experimental, before/after, with control, Public school pupils, [9–13], i: 45.5% ♂, c: 43.0% ♂, Denmark; n = 490 (i: 332, c: 158)	Education outside the classroom, 9–10 months, 2–7 h per week over	No intervention	Number of pupil's peer affiliation groups; Size of pupil's peer affiliation groups; New affiliations; Lost affiliations; Standardised degree centrality (%) (SCM)
(Bølling et al., 2019a)	Quasi-experimental, before/after, with control, Public school pupils, i: $\bar{x}$ = 10.9 (SD: 0.9), c: $\bar{x}$ = 10.8 (SD: 0.6) years, i: 46.6% ♂, c: 43.3% ♂, Denmark; n = 631 (i: 511, c: 120)	Education outside the classroom, 9–10 months, 2–7 h per week over	No intervention	Emotional symptoms; Conduct problems; Hyperactivity/Inattention; Peer relationship problems; Prosocial Behaviour (SDQ)
(Gustafsson, 2012)	Before/after, with control, Elementary school pupils, urban/urban fringe, $\bar{x}$ = 8.3 [6–12] years, i: 56.2% ♂, c: 51.4% ♂, Sweden; n = 230 (i: 121, c: 109)	Education outside the classroom, 6 months, 15 sessions of min. 4 h	No intervention	Emotional symptoms; Conduct problems; Hyperactivity/Inattention; Peer relationship problems; Prosocial Behaviour (SDQ)
(Kim et al., 2012)	Before/after, with control, Children with intellectual disabilities, [7–9] years, 41,7% ♂, South Korea; n = 24 (i: 12, c: 12)	Horticultural Therapy, 6 months, 40 min weekly	Treatment as usual	Self-assertion; Self-control; Cooperation; Responsibility; Attention; Oppositional; Hyperactivity; Inattention (CTRS-R)
(Kuo et al., 2018)	Within-subjects, with cross-over, no randomisation, Environmental magnet school pupils, [9–10] years, N.R. % ♂, USA; n = N.R. (2 clusters)	Lesson in nature, 10 weeks, weekly 40 min session	Indoor lesson, 10 weeks, weekly 40 min session	Classroom engagement (teacher, student and observation assessed), Teacher redirects (observation), Composite index of engagement (Developed by authors)
(Largo-Wight et al., 2018)	Within-subjects, with cross-over, no randomisation, Public school pupils, [5–6] years, 54% ♂, USA; n = 37	Outdoor classroom, 6 weeks, every second day	No intervention, every second day	Number students off-task; Periods students off-task; Teacher redirects; Periods teacher redirects (Developed by authors, observation)
(Monti et al., 2019)	Natural experiment, before/after, with control, Children in nurseries, [1–3] years, 50% ♂, Italy; n = 160 (i: 76, c: 84)	Outdoor education program, 6 months	No intervention	Social and Emotional development (KBDT)
(Mygind, 2009)	Natural experiment, within-subjects, no cross-over, Elementary school pupils, from school practicing EOtC, $\bar{x}$ = 12 (SD: N.R.), 26% ♂, Denmark; n = 19	Education outside the classroom, three years, one day per week	No intervention	Quality of peer relations (Developed by author, child-rating)
(Ramshini et al., 2018)	RCT, Children diagnosed with Autism Spectrum disorders, [3–7] years, 87.3% ♂, Iran; n = 14 (i: 7, c: 7)	Nature therapy, duration N.R., 10 sessions	Treatment as usual	Sensory processing (SEC)
(Raney et al., 2019)	Before/after, with control, Title 1 elementary school pupils, grade [1–5], i: 42.8% ♂, c: 44.1% ♂, USA; n = 437 (i: 355, C: 82)	School ground greening	No intervention	Antisocial behaviour (SOCARP)
(Reed et al., 2013)	Within-subjects, with cluster-level, randomised cross-over, Secondary school pupils, [11–12], N. R. % ♂,; n = 86	Nature run, 10–20 min	Lap around school, 10–20 min	Self-esteem (RSES)
(van den Berg et al., 2017b)	Before/after, with control, Elementary school children, i: $\bar{x}$ = 9, c: $\bar{x}$ = 9.2 [7–10] years, i: 60% ♂, c: 52% ♂, The Netherlands; n = 170 (i: 84, c: 86)	Green wall	No intervention	Self-image (HSPPC)
(van Dijk-Wesselius et al., 2018)	Natural experiment, before/after, with control, Elementary school pupils, urban area residents, i: $\bar{x}$ = 8.5 (SD: N.R.), c: $\bar{x}$ = 8.6 (SD: N.R.) years, i: 48.6% ♂, c: 52% ♂, The Netherlands; n = 607 (i: 351, c: 355)	School ground greening	No intervention	Prosocial orientation; Prosocial behaviour; Peer relationship problems; Social support in friendships; Emotional functioning (PedsQL)
(Wood et al., 2014)	Within-subjects, with cluster-level, randomised cross-over, Urban primary school pupils, $\bar{x}$ = 8.6 (SD: 0.3) years, 48% ♂, UK; n = 25	Free playtime during morning and lunch break, at green school field	Free playtime during morning and lunch break, at school playground	Self-esteem (RSES, slightly modified)
(Zachor et al., 2017)	Before/after, with control, Children with autism spectrum disorder (ASD), i: $\bar{x}$ = 5.6 (SD: 0.9), c: $\bar{x}$ = 5.0 (SD: 1.0) years, 78.4% ♂, Israel; n = 51	Outdoor adventure program, 13 weeks, weekly 30 min sessions	Treatment as usual	Social impairment, Social awareness, Social cognition, Social communication, Social motivation, Autistic mannerisms (SRS), Adaptive behaviours, Communication, Socialisation (VABS)

AAMD-ABSCA; *The American Association on Mental Deficiency Adaptive Behavior Scale For Children and Adults (Parts 1 and 2)*, CTRS-R; *Connors Teacher Rating Scale – Revised Short Version,* HSPPC; *Harter's Self-Perception Profile for Children*, KBDT; *The Kuno Beller Development Tables (Italian translation and adaptation by Mantovani, 1995)*, PedsQL; *Pediatric Quality of Life Inventory,* RSES; *Rosenberg's Self-Esteem Scale*, SCM; *Social Cognitive Mapping*, SDQ; *Strengths and Difficulties Questionnaire*, SEC; *The Sensory Evaluation Checklist*, SOCARP; *System for Observing Children's Activity and Relationships during Play*, SRS; *The Social Responsiveness Scale*, VABS; *The Vineland Adaptive Behaviors Scale*, YLSI; *Youth Life Skills Inventory*

over the age of six (73.3%, n = 105).

3.4.2.2. Synthesis. Adaptive behaviours associated positively with availability of and spending time in green space in 22.2% (n = 36) of the analyses from observational and experimental studies. Maladaptive behaviours associated inversely with green space in 14.9% (n = 67) of the analyses. In the following, we refer to both adaptive and maladaptive behaviours simply as adaptive behaviours.

Table 3
Risk of bias in observational studies.

ID	Selection	Confounding	Attrition	Detection (exposure)	Detection (outcome)	Reporting	Statistics
(Amoly et al., 2014)	– NR	+	+	+ / – NR	++ / +	+	– NR
(Balseviciene et al., 2014)	– NR	+	– NR	+ / – NR	++	– NR	– NR
(Carrus et al., 2012)	– NR	– NR	– NR	– NR	– NR	– NR	– NR
(Carrus et al., 2015)	– NR	– NR	– NR	––	– NR	– NR	– NR
(Christian et al., 2017)	++	++	+	– NR	+	++	+
(Donovan et al., 2019)	++	++	+	– NR	+	++	++
(Faber Taylor et al., 2001)	– NR	– NR	– NR	– NR	– NR	+	+
(Faber Taylor et al., 2002)	+	– NR	– NR	– NR	– NR	+	+
(Feng & Astell-Burt, 2017)	– NR	+	– NR	– NR	++	+	+
(Flouri et al., 2014)	+	++	++	– NR	+	+	+
(Kuo & Faber Taylor, 2004)	– NR	+	– NR	– NR	– NR	+	– NR
(M. Lee et al., 2019)	+	++	– NR	++	++	++	+
(Mårtensson et al., 2009)	– NR	+	+	– NR	++	++	+
(Madzia et al., 2019a)	– NR	++	+	+	+	––	– NR
(Markevych, Tiesler, et al., 2014)	– NR	+	N.A.	– NR	++	+	++
(Markevych et al., 2018)	– NR	– NR	++	+	++	++	++
(McCracken et al., 2016)	– NR	– NR	++	– NR	– NR	++	– NR
(McEachan et al., 2018)	– NR	++	+	++ / – NR	++	+	– NR
(Richardson et al., 2017)	– NR	+	– NR	– NR	++ / +	+	+
(Scott et al., 2018)	– NR	– NR	++	– NR	++	+	– NR
(Tillmann, Clark, et al., 2018)	– NR	++	++	– NR	+	+	– NR
(Van Aart et al., 2018)	– NR	– NR	+	– NR	+	– NR	+
(Wells, 2000)	– NR	––	– NR	– NR	+	+	++
(Wells & Evans, 2003)	– NR	+	– NR	– NR	– NR	+	+
(Wu & Jackson, 2017b)	– NR	+	N.A.	+	– NR	+	++
(Zach et al., 2016)	++	+	++	– NR	+	+	+

'++'; Definitely low risk of bias, '+'; Probably low risk of bias, '– NR'; Probably high risk of bias/N.R., '––'; Definitely high risk of bias, N.A.; Not applicable.
The use of '/' signifies that the individual study included multiple exposure or outcome assessments and that these were considered to involve different risk of bias.

Table 4
Risk of bias in experimental studies.

ID	Selection (randomisation)	Selection (allocation)	Performance	Attrition	Detection (exposure)	Detection (outcome)	Reporting	Statistics
(Ackley D & Cole L, 1987)	+	++	+	– NR	– NR	+	+	+
(Block et al., 2012)	––	+	+	– NR	– NR	– NR	+	+
(Bølling, Pfister, et al., 2019)	– NR	– NR	+	– NR	++	– NR	++	+
(Bølling, Niclasen, et al., 2019)	– NR	– NR	+	– NR	++	+	++	+
(Gustafsson, 2012)	––	– NR	– NR	– NR	– NR	+	+	+
(Kim et al., 2012)	––	– NR	– NR	– NR	– NR	– NR	+	+
(Kuo et al., 2018)	––	– NR	––	+	– NR	– NR	+	– NR
(Largo-Wight et al., 2018)	––	– NR	– NR	– NR	– NR	– NR	––	+
(Monti et al., 2019)	––	– NR	––	– NR	– NR	– NR	––	– NR
(E. Mygind, 2009)	––	+	– NR	– NR	– NR	– NR	+	+
(Ramshini et al., 2018)	+	+	––	– NR	– NR	– NR	– NR	– NR
(Raney et al., 2019)	––	– NR	+	– NR	– NR	– NR	– NR	+
(Reed et al., 2013)	+	+	+	– NR	+	+	– NR	+
(M. van den Berg et al., 2017)	––	– NR	– NR	– NR	+	– NR	+	– NR
(van Dijk-Wesselius et al., 2018)	––	– NR	+	– NR	– NR	+ / – NR	– NR	++
(Wood et al., 2014)	+	+	– NR	– NR	– NR	– NR	+	– NR
(Zachor et al., 2017a)	+	+	– NR	– NR	– NR	+ / – NR	+	– NR

'++'; Definitely low risk of bias, '+'; Probably low risk of bias, '– NR'; Probably high risk of bias/N.R., '––'; Definitely high risk of bias, N.A.; Not applicable.
The use of '/' signifies that the individual study included multiple outcome assessments and that these were considered to involve different risk of bias

A higher proportion of analyses (28.5%, $n = 28$) encompassing children under the age of six suggested positive associations with green space than when including children over the age of six (13.0%, $n = 77$). The proportion of positive findings was higher in analyses from experimental studies (42.9%, $n = 14$) compared to observational studies (13.2%, $n = 91$). Amongst the analyses from observational studies, there were no cases indicating that availability of greenery in the immediate surroundings associated with improved adaptive behaviours ($n = 6$), one suggesting positive associations within intermediate buffers ($n = 14$) and 11.7% with greenery in the surrounding neighbourhood ($n = 43$). One of 13 analyses investigating availability of residential green space in unspecified locations reported positive findings. Excluding rural samples did not reveal differential findings.

3.4.2.3. Stratification. Stratification by maternal level education provided inconsistent patterns; Shorter distances to urban green space associated with decreased conduct problems and increased prosocial behaviour amongst children in the lowest education group, meanwhile no difference was observed for children with highly educated mothers (Balseviciene et al., 2014). Likewise, having access to a private garden associated with lower conduct problems amongst children from families with low but not high levels of education (Richardson et al., 2017). Residential vegetation, however, associated with decrements in conduct problems and prosocial behaviour amongst children of mothers in the highest education group, whereas no significant differences were observed for children of mothers of low education (Balseviciene et al., 2014). Finally, the proportion of natural space within the child's postcode of residence, but not proportion park space or having access to private gardens, associated positively with prosocial behaviours amongst children of highly educated families, but not children from low education households (Richardson et al., 2017). As such, while there are some suggestions that children from low education homes may obtain

Table 5
Summary of results from unstratified analyses. Number of positive findings of all findings.

	Relationships		Adaptive behaviours	Competence	Emotion management		Behavioural inhibition		Thoughts of self	Compound	Psychopathology		Total
	G	*C*	*G & C*	*G*	*G*	*C*	*G*	*C*	*G*	*G*	*ASD*	*ADHD*	
Observational													
Home	1:1	–	1:2	–	0:1	–	1:1	0:1	–	1:1	–	–	4:7
Residential	2:24	–	9:80	0:2	8:66	–	8:42	–	1:2	9:31	1:4	7:13	53:264
	1:9		*4:41*		*2:35*		*7:24*			*7:17*		*6:12*	
Residential & school surroundings	0:1	–	0:2	–	0:1	–	1:3	–	–	1:1	–	1:1	3:9
School	0:1	4:7	1:3	–	–	2:4	2:3	–	–	–	–	–	9:18
School surroundings	0:1	–	0:2	–	0:1	–	0:3	–	–	0:1	–	0:1	0:9
Other	2:3	–	1:2	–	0:2	–	0:3	1:1	1:1	1:1	–	3:4	9:17
Experimental													
Home	–	–	–	–	–	–	–	–	–	–	–	–	–
Residential	–	–	–	–	–	–	–	–	–	–	–	–	–
School	2:5	1:5	2:6*	0:1	0:3	–	0:2	5:9	0:3	1:2	–	–	11:36*
School surroundings	–	–	–	–	–	–		–	–	–	–	–	–
Treatment	–	–	2:5	4:5	1:1	–	1:3	–	–	–	1:1	0:1	9:16
Other	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	7:36	5:12	18:105	4:8	9:75	2:4	13:60	6:11	2:6	13:37	2:5	11:20	

G: Generic measures, *C:* Contextually bound measures.
Cursive indicates restricted analyses, i.e. analyses including only low risk of bias studies.
* Three additional analyses investigating mixed school + treatment intervention (two of three positive).

some differential benefits regarding adaptive behaviours from green space, patterns are inconsistent. Stratification by sex (Markevych et al., 2014b) and race (McEachan et al., 2018) did not consistently reveal differential associations, although Richardson et al. (2017) found that conduct problems were lower amongst boys and not girls in association with having access to a private garden, and prosocial behaviours amongst girls but not boys associated positively with postcode green space.

3.4.3. *Social cognition, empathy, and competence*

3.4.3.1. Characteristics of analyses. One observational study and two experimental studies investigated aspects of social competence. The observational study investigated residential greenery. The experimental studies were set in educational contexts including school ground greening (van Dijk-Wesselius et al., 2018) and an outdoor adventure programme (Zachor et al., 2017). However, the latter was applied as a treatment for children with ASD and is therefore included in Table 5 within the context of treatment (Zachor et al., 2017). Sample sizes ranged from 51 to 23,395 and were rated some or low risk of bias. These findings were predominantly derived from analyses encompassing children under the age of six years (87.5%, $n = 8$).

3.4.3.2. Synthesis. Half of the analyses ($n = 8$) from these studies indicated positive effects and associations. Given the small number of analyses, it was not possible to identify potential stratifying patterns across the literature.

3.4.4. *Emotion management and expression*

3.4.4.1. Characteristics of analyses based on generic measures. Generic emotion management and expression, including measures pertaining to anxiety, depression, somatisation, as well as emotional wellbeing and maturity, was investigated in four experimental and ten observational studies. Most analyses from observational studies investigated availability of residential greenery (93.0%, $n = 71$) amongst children over the age of six (81.7%, $n = 71$). Sample sizes ranged from 224 to 23,395 children in individual studies. Several studies linked unique child data with local community exposure data (from 46 to 143 spatial units). Although the studies were generally rated positively with few to some risk of bias concerns, these ecological exposure assessments were considered less sensitive and therefore to possibly involve risk of detection bias. Some concerns regarding selection due to unclear recruitment strategies and population representativity were also reported. The experimental studies investigated education outside the classroom (Bølling et al., 2019a; Gustafsson, 2012), school ground greening (van Dijk-Wesselius et al., 2018), and nature therapy provided to small children diagnosed with ASD (Ramshini et al., 2018). Sample sizes ranged from 14 to 631. All studies involved some or serious risks of bias.

3.4.4.2. Synthesis. Across analyses from experimental and observational studies, 12.0% indicated positive findings. One of four analyses from the experimental studies displayed benefits, whereas the proportion within observational studies was 11.3% ($n = 71$). When focusing on analyses derived from urban samples only, 16.6% indicated positive findings ($n = 42$). No difference in the proportions of positive findings pertaining to type of study, age groups, or green space buffer was apparent.

3.4.4.3. Stratification. Stratification by maternal level of education (Balseviciene et al., 2014; Richardson et al., 2017) and sex (Markevych et al., 2014b; Richardson et al., 2017) did not reveal differential associations. Notably, the proportion of vegetation within 100, 300, and 500 m buffers associated with reduced internalising difficulties for the south Asian subgroup of the Born in Bradford Study, whereas no such association was observed for the Caucasian subgroup (McEachan et al., 2018).

3.4.4.4. Characteristics and synthesis of analyses based on contextual measures. Regarding contextual indices of emotion management and expression (e.g. crying episodes and comfort capacity), two of four analyses from two unique studies (Carrus et al., 2012, 2015) suggested positive associations. The studies included 16 and 39 participants and were considered at high risk of bias.

3.4.5. *Behavioural inhibition*

3.4.5.1. Characteristics of analyses. Analyses from a total of ten observational studies predominantly investigated associations between generic indicators of behavioural inhibition and availability of residential greenery (76.4%, $n = 55$). Sample sizes ranged from 198 to 6384.

Studies were generally rated positively with few to some risk of bias concerns. Some concerns regarding selection due to unclear recruitment strategies and population representativity were reported. Three experimental studies investigated interventions set in or around educational institution settings; education outside the classroom (Bølling et al., 2019a; Gustafsson, 2012) and horticultural therapy involving children with intellectual disabilities (Kim et al., 2012). Sample sizes ranged from 24 to 631. Studies involved some or serious risk of (performance, selection, and/or exposure characterisation) bias. Most analyses included children over the age of six (83.3%, $n = 60$).

3.4.5.2. Synthesis. Across analyses from experimental and observational studies, 21.7% ($n = 60$) indicated positive associations. Analyses including children under the age of six more often reported positive associations (50.0%, $n = 10$). Amongst the analyses derived from observational studies, a higher proportion of positive findings was observed for greenery in the immediate surroundings around the child home (2:4) compared to intermediate (0:4) and neighbourhood buffers (17.6%, $n = 17$), as well as location-unspecified greenery (10%, $n = 10$). No difference in the proportion of positive associations and effects was observed in experimental versus observational studies, nor when excluding rural samples.

3.4.5.3. Stratification. We observed some evidence for differential associations according to stratification by maternal level of education, with children with mothers of low but not high educational attainment accruing reductions in hyperactivity and inattention difficulties (Balseviciene et al., 2014). However, this was not consistent across types of green space exposures within the study, nor was any difference observed by Richardson et al. (2017) who, however, observed that having access to a private garden associated with lower hyperactivity and inattention difficulties amongst child from low but not high education households.

Three studies investigated differential associations with residential greenery in the immediate (Faber Taylor et al., 2002) and neighbourhood surroundings (Markevych et al., 2014b; Richardson et al., 2017) related to child sex. Interestingly, Faber Taylor et al. (2002) found that girls' performance-based behavioural inhibition was positively associated with more greenery whereas no such pattern was discerned for boys. Likewise, Richardson et al. (2017) found that residential green space associated positively girls' but not boys' hyperactivity and inattention difficulties. Conversely, Markevych et al. (2014b) reported that boys', but not girls', hyperactivity and inattention symptoms were inversely associated with shorter distances to nearest urban green spaces.

3.4.5.4. Characteristics and synthesis of analyses based on contextual measures. Regarding contextual indices of behavioural inhibition, e.g. classroom engagement or ability to stay on task after specific types of activities in green or built environments, 54.5% ($n = 11$) of the analyses from three unique studies (Faber Taylor et al., 2001; Largo-Wight et al., 2018; Kuo et al., 2018) suggested positive associations. Sample sizes ranged from two clusters including an unknown number of students to 96 participants. These studies were all considered at high risk of bias.

3.4.6. Thoughts of self

3.4.6.1. Characteristics of analyses. A small body of research focusing on perceptions of self, e.g. self-esteem and -image, was identified. The analyses from the two observational studies investigated the availability of residential greenery ($n = 2$) or unspecified locations ($n = 1$). Sample sizes ranged from 276 to 337. Studies involved some or serious risk of bias due to possible selection, poor control for confounding, and questionable outcome and exposure assessment. The three experimental studies were set in school contexts. Sample sizes ranged from 25 to 170. Studies had low few, moderate, and high risk of bias. All children were over the age of six.

3.4.6.2. Synthesis. Two of three of the analyses from observational studies suggested positive associations between green space and thoughts of self. Neither of the experimental studies reported any benefits for the children's self-perception following a 20-min nature run (Reed et al., 2013), free play in a green school field (Wood et al., 2014), or the installation of a green wall in the children's classroom (van den Berg et al., 2017a). Due to the small number of studies we did not stratify results further.

3.4.7. Compound

3.4.7.1. Characteristics of analyses. The compound category encompasses indicators that assess a number of competences, behaviours, and symptoms, indicated, for example, by the total difficulties scale within the SDQ (Goodman and Goodman, 2009). Identified analyses were predominantly derived from observational studies (94.9%, $n = 36$), and investigated associations with availability of residential greenery (86.0%, $n = 36$). The observational studies included from 224 to 5117 participants and were predominantly considered at low risk of bias, although a few studies had some concerns. Sample sizes in the two experimental studies were 160 and 230. These studies were considered at high risk of bias. Most analyses included children over the age of six (68.9%, $n = 36$).

3.4.7.2. Synthesis. Across these broad assessments of socioemotional factors, 35.1% ($n = 37$) of the analyses indicated positive findings. When excluding analyses including rurally residing children, the proportion of positive findings was higher (40.0%, $n = 20$). We observed no differences in proportions of positive findings according to age or the size of green space buffer.

3.4.7.3. Stratification. Stratification by maternal level of education suggested that lower distances to nearest urban parks associated with reduced problem behaviours amongst the low maternal education subgroup (Balseviciene et al., 2014). No such association was observed for children of mothers with longer education, nor when testing for associations with the proportion of vegetation 300 m from home with either subgroup. This association seemed to be driven largely by the association with reduced hyperactivity and inattention (see Section 3.4.2) since the other SDQ scales were not found to correlate with the exposure. Similarly, having access to a garden associated with reduced total difficulties for children in low but not high education families (Richardson et al., 2017).

Markevych et al. (2014b) reported that boys', but not girls', SDQ sum score was inversely associated with shorter distances to nearest urban green spaces. This again correlated with findings pertaining to hyperactivity and inattention symptoms. Richardson et al. (2017) also identified sex-related differences in associations with residential green space but these weren't consistent across the two indicators used; natural space associated with total difficulties only for the girls and park space only for boys. McEachan et al. (2018) found no evidence for racial differences in associations between greenery and the SDQ sum score.

3.4.8. Child psychopathology

3.4.8.1. Characteristics of ADHD analyses. One experimental and six observational studies have investigated how green space interacts with ADHD-specific symptoms and prevalence. The experimental study included 24 participants and was considered at high risk of bias. The observational studies included from 17 to 49,956 participants and were considered at low or high risk of bias.

3.4.8.2. Synthesis. Across the analyses, 55% ($n = 20$) reported associations with reduced ADHD symptoms and prevalence. If focusing exclusively on low risk of bias studies, this proportion was decreased to 35% ($n = 15$). These studies predominantly investigated the associations between ADHD and availability of residential greenery (65.0%, $n = 20$).

3.4.8.3. Stratification. In a New Zealand study, Donovan et al. (2019) found that the proportion of vegetation within the child's mesh block of residence was associated with reduced risk of ADHD for boys but not girls, for children who had always resided in urban but not rural areas and for children of European, but not Maori descent.

3.4.8.4. Characteristics and narrative synthesis of ASD analyses. Two studies investigated associations between ASD prevalence and the proportion of forest, grassland, tree canopy, and road-adjacent tree canopy within the child's residential district (Wu and Jackson, 2017) and ASD symptoms (Zachor et al., 2017). The studies included 543 districts and 51 participants and were rated low and moderate risk of bias, respectively. Zachor et al. (2017) found that participation in a 13-week outdoor adventure program reduced ASD mannerisms. Other ASD-sensitive social competences were also investigated and reviewed as part of Section 3.4.6.

3.4.8.5. Stratification. Wu and Jackson (2017) found that one of four of the green space features, i.e. proportion grassland, was associated with reduced ASD prevalence. However, within the quartile with the highest density of roads, all exposures were associated with reduced ASD prevalence. This was not observed in the low-density quartile.

3.5. Risk of bias across studies

Across the body of evidence, some issues appeared more frequently, contributing to recurrent negative risk of bias assessments (see Figs. 2 and 3). Selection was repeatedly considered problematic or possibly problematic; most often, recruitment strategies and non-participation were not reported in sufficient detail to evaluate if skewed representation was likely or present. Under the assumption that children with specific characteristics (e.g. socioeconomics or ethnicity), would be more or less likely to benefit from exposure to green space, skewed representation may bias results away and towards the null. Attrition was also not systematically reported and discussed.

In experimental studies, randomisation was used only sporadically introducing risks of poor comparability of groups at baseline and in development trajectories. Experimental studies rarely reported on intervention compliance and fidelity, a considerable source of bias possibly skewing results towards or away from the null.

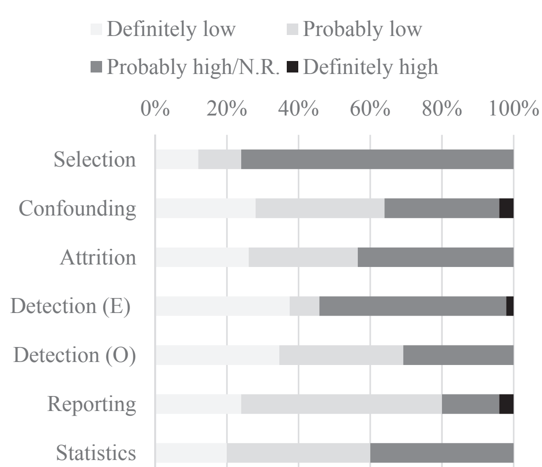

Fig. 2. Risk of bias across observational studies. Note: E refers to exposure and O to outcome detection bias.

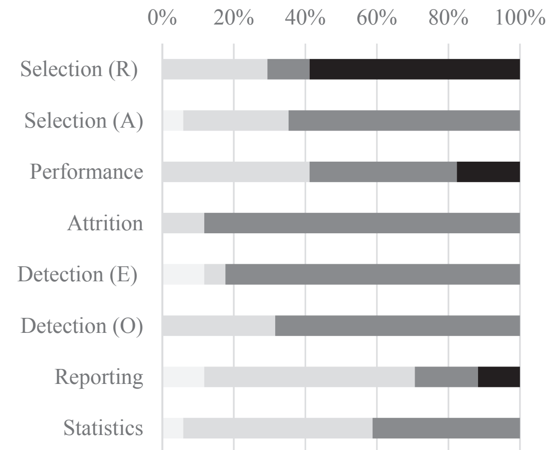

Fig. 3. Risk of bias across experimental studies. Notes: R refers to randomisation and A to allocation bias. E refers to exposure and O to outcome detection bias.

We identified two important sources of statistical bias. Firstly, many experimental studies used data from participants clustered in institutional settings, and observational studies used exposure data from larger spatial units (e.g. postcode areas), appended to the child data. Due to the statistical modelling used, assumptions of independence of observations were frequently violated. This is perhaps more likely to present a problem in data derived from the classroom-clusters in experimental studies which may be expected to have a stronger bearing on the SDO's, if any, than, for example postcode areas. It remains, however, that the use of ecological exposure data in the observational studies reduces statistical power and introduces risks of type 1 and type 2 errors. Secondly, observational studies frequently included large numbers of exposures and outcomes without statistical adjustment for multiple testing, introducing a risk of type 1 errors.

Precise *p*-values were not generally reported. As such, results derived from the available *p*-values would represent a selected body of evidence. Since such a representation would likely be non-representative and possibly misguiding, we did not compute a *p*-curve analysis.

3.6. Additional analyses: Proximal outcomes

Here we discuss the more extensively researched proximal outcomes (see Table 6 for a summary of the findings and Fig. 4 for an illustration of the possible pathways).

For a full list of identified proximal outcomes, we refer to Appendix I. In Appendix I, the identified outcomes are listed with short descriptions, references to the literature investigating the relationship with contact with nature, and references to independent research demonstrating an association or effect of P-SDO with/on SDO.

3.6.1. Cognition

3.6.1.1. Characteristics of analyses. We identified 38 exposures including 84 analyses, extracted from ten experimental and eight observational studies. Analyses from observational studies predominantly investigated availability of green space ($n = 58$) most which was categorised as residential ($n = 50$). Experimental studies investigated nature-based educational or green recess interventions set in a school context ($n = 11$), treatment ($n = 2$), or unspecified locations ($n = 7$). Most analyses included children over the age of six ($n = 45$) or children aged both under and over six ($n = 2$). Only one analysis from an experimental study and 18 from observational studies included children under the age of six.

Table 6
Summary of P-SDO results from unstratified analyses. Number of positive findings to all findings.

	Cognition						Movement behaviours						Screen time
	Attention	Working memory	Inhibitory control	Cognitive flexibility	Global measures		MVPA	VPA	MPA	LPA	Sedentary time	Sleep	
					Q	*P*							
Observational													
Home	–	–	–	–	–	–	1:5	–	–	–	–	–	–
Residential	1:19	0:2	6:18	–	0:3	3:5	1:2	–	0:2	0:1	1:2	–	5:8
Residential & school surroundings	–	–	–	–	–	–	–	–	–	–	–	–	–
School	–	–	–	–	1:1	–	4:9*	0:6*	2:3	2:3	2:5	1:1	–
School surroundings	2:2	4:4	–	–	–	–	–	–	–	–	–	–	–
Other	1:2	3:4	–	–	–	–	5:20	2:3	–	–	–	–	–
Experimental													
Home	–	–	–	–	–	–	–	–	–	–	–	–	–
Residential	–	–	–	–	–	–	–	–	–	–	–	–	–
School	3:6	1:1	1:1	1:1	1:2	–	6:7	2:3	3:3	1:3	0:1	–	–
School surroundings	–	–	–	–	–	–	–	–	–	–	–	–	–
Treatment	–	1:1	1:1	–	–	–	–	–	–	–	–	–	–
Other	2:4	1:2	0:1	–	–	–	–	–	–	–	–	–	–

Continued.

	Healthy weight			Stress			Mood	Physical wellbeing	Motor skills	Language & communication skills
	Body composition, continuous	Obesity/ overweight	Obesity	Self-report	Acute	Cumulative				
Observational										
Home	–	–	–	–	–	–	–	–	–	–
Residential	7:32	7:20	3:11**	–	–	3:12	14:32	1:4	4:6	1:3
Residential & school surroundings	–	–	–	–	–	–	–	–	–	–
School	0:1	–	1:1	1:2	0:1	–	2:2	0:2	–	–
School surroundings	0:1	–	–	–	–	–	–	–	–	–
Other	–	–	–	–	–	–	–	0:1	–	–
Experimental										
Home	–	–	–	–	–	–	–	–	–	–
Residential	–	–	–	–	–	–	–	–	–	3:5
School	–	–	–	0:4	3:4	–	0:2	0:1	6:10	–
School surroundings	–	–	–	–	–	–	–	–	–	–
Treatment	–	–	–	–	–	–	0:1	–	–	3:3
Other	–	–	–	–	–	–	–	–	–	–

P: Performance-based, *Q*: Questionnaire-based.
Note: Play, birth outcomes, allergy, and asthma not included in this table. Play is mainly based on descriptive studies. Categorising these as positive or insignificant would not be appropriate. Meta-analyses exist for birth outcomes, allergy, and asthma.
* One analysis negative.
** Three analyses negative.

3.6.1.2. Synthesis. When scoping these studies, we noticed a difference in the proportion of positive versus non-significant (and in very limited cases, negative) results reported in papers based on observational and experimental design, and we therefore present these results separately.

Across 60 analyses from observational studies, 17.4% indicated positive associations with attention (n = 23, all over 6), 70% with working memory ($n = 10$, all over 6), and 33.3% with inhibitory control (n = 18, all under 6). One of four and three of five analyses indicated positive associations with global measures of cognition measured via questionnaires and task performance, respectively. None reported cognitive flexibility. We identified no apparent differences in these findings according to buffer size.

Across analyses from experimental studies, 50% reported positive associations between participating in the nature-based interventions and attention ($n = 10$), three of four with working memory, and two of three with inhibitory control. One of one analysis indicated positive associations with cognitive flexibility and one of two analyses indicated positive associations with global cognitive function, as measured via child- and teacher-report. None reported global cognitive function measured via child performance.

3.6.1.3. Stratification. Only one study stratified findings. Stratification by sex revealed that girls' global cognitive function, measured via performances in a battery of tasks, was associated with green views from their home address, whereas no such association was observed for boys (Faber Taylor et al., 2002).

3.6.2. Play

3.6.2.1. Characteristics of analyses. The studies investigating play were mostly based on descriptive comparisons of frequency and duration of various overlapping and non-overlapping types of play within spatial segments defined by variable features (i.e. 'green refuges' versus 'non-green refuges', or 'naturalised playground' versus 'manufactured', 'contemporary,' or 'traditional' playgrounds). Eleven analyses from 11 studies included predominantly children under the age of six ($n = 9$) and were localised in preschool settings ($n = 7$).

3.6.2.2. Narrative synthesis. The proportions of verbal and socio-dramatic play, that is pretend or dramatic play within a group of children, within natural spatial segments was found to be both higher

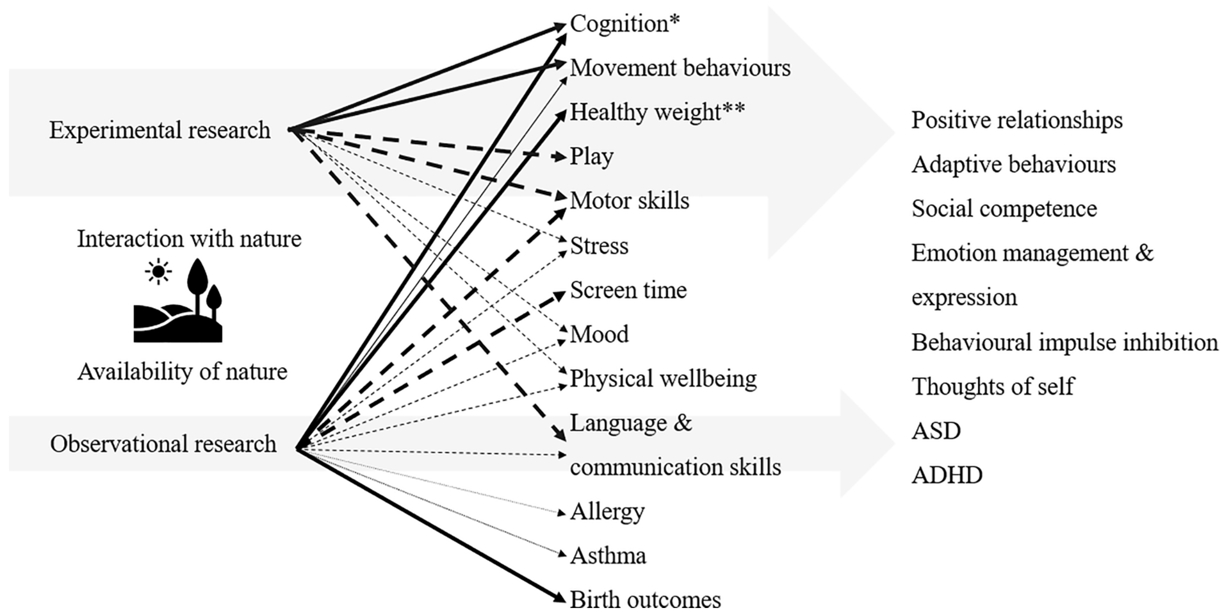

Fig. 4. Bidirectional pathways between spending time in and availability of green space in experimental and observational research, respectively, and proximal outcomes and socioemotional function and development. Note: Fat lines to P-SDO's and SDO's indicate higher consistency in associations. Dotted lines indicate that the evidence-base is small. * Findings within cognition domain mostly consistently positive, however inhibitory control and purer attention measures and were not. ** Only reductions in overweight and obesity for children over age six were consistent.

(Drown and Christensen, 2014; Wight et al., 2016), similar (Kirkby, 1989), and lower (Dowdell et al., 2011) compared to manufactured playgrounds or playground segments. None of these studies utilised any form of comparative statistics to infer significance.

No differences were observed based on comparative statistics in the relative frequency of functional and constructive play, sociodramatic play, and play with rules in a naturally structured versus contemporary playground (Luchs and Fikus, 2013). However, the duration of play segments, across play types, was observed to be prolonged in the naturally structured playground. A similar observation was made by Morrissey et al. (2017). Indeed, the children were engaged in longer bouts of sociodramatic play in a naturalised playground compared to a traditional playground. Similarly, Faber Taylor et al. (1998) found that children of unspecified ages were more likely to engage in creative forms of play (i.e. pretend and creative rule-bound play) when using high-vegetation outdoor spaces compared to low-vegetation outdoor spaces. No such difference was observed for a compound play category that included rule-bound conventional, exploratory, functional, and constructional types of play.

Lindholm (1995) found that pretend play was most frequent in school yards with presence of or proximity to greenery, although highlighted that within these school yards pupils also used hardened surfaces more. Similarly, Robertson et al. (2019) suggested that vegetation and natural loose parts in conjunction with man-made resources, as well as opportunities for seclusion, no overcrowding, sufficient linking pathways, and an open-ended design, provided optimal opportunities for sociodramatic play. This was supported by higher levels of imitative role play, make believe with objects, interaction and verbal communication, as well as longer play perseverance, in the naturalised playground compared to a traditional playground. With many of the above studies being based on comparisons across playgrounds categorised according to a predominance or absence/lesser degree of vegetation, it is possible that the findings could be attributed not only to vegetation, but also the integration of vegetation with man-made features, as well as other design features.

3.6.3. *Movement behaviours*

3.6.3.1. Characteristics of analyses. We identified 79 analyses from seven experimental and 30 observational studies. Movement behaviours were mainly measured via accelerometry and, in a few instances, self-report and observation. Analyses from observational studies investigated home (n = 5), neighbourhood (n = 18), institutional (n = 21, surrounding institution n = 1), and locality unspecified greenery (n = 20). Experimental studies all investigated school-based interventions involving, for example, teaching activities in gardens (Rees-Punia et al., 2017) and other green areas (e.g. Dettweiler et al., 2017; Schneller et al., 2017) or school ground greening renovations (Raney et al., 2019; van Dijk-Wesselius et al., 2018). Ages predominantly ranged from six to 12 years (77.2%, n = 79).

3.6.3.2. Synthesis. Amongst the observational studies, 30.5% reported increased time (across the day or segment-wise) spent in moderate-to-vigorous physical activity (MVPA) (n = 36, <6: 27.3%, >6: 33.3%), 22% with vigorous PA (VPA) (n = 9, all > 6), 40% with moderate PA (MPA) (n = 5, all > 6), 50% with low-intensity PA (LPA) (n = 4, <6: 0:1, >6: 2:3), and 42.8% with reductions in sedentary time (n = 7, <6: 1:3, >6: 2:4). We did not observe any patterns in regard to results and buffer sizes or context of exposure.

Across the experimental studies, more MVPA was reported in intervention conditions in 85.7% of the studies (n = 7), two of three studies reported higher VPA, three of three more MPA, and one of three more LPA. Only one study investigated associations with sedentary time, but found no discernible difference (Wells et al., 2014). One study reported that night sleep duration, as perceived by parents, was associated with a high quality preschool outdoor environment, defined by amount of vegetation as a core feature amongst other parameters (Söderström et al., 2013).

3.6.3.3. Stratification. Stratification by sex was the most common form of stratification used across observational and experimental studies, with boys more frequently achieving higher levels of MVPA (2:5 versus 0:5), VPA (1:3 versus 0:3), and MPA (1:1 versus 0:1) in green space. No difference could be discerned for LPA (0:1 versus 0:1).

3.6.4. Screen time

3.6.4.1. Characteristics of analyses. We identified four observational studies. Non-stratified analyses derived from these studies all included children over the age of six ($n = 8$), however we also identified 14 stratified analyses (by sex, age, and time of the week). Five of these stratified analyses included children under the age of six and four children over and under six years. All analyses concerned availability of residential green space ($n = 21$).

3.6.4.2. Synthesis. Across non-stratified analyses, 62.5% ($n = 8$) indicated positive associations between availability of green space and screen time.

3.6.4.3. Stratification. Stratification by age suggested that availability of urban green space reduced screen time for children over, but not under, the age of six years (Akpinar, 2017), however this pattern was not observed consistently (Sanders et al., 2015c). Stratification by sex suggested that residential greenery associated with reduced TV time on the weekends amongst boys but not girls. No association was observed for girls or boys during the weekdays (Sanders et al., 2015c).

3.6.5. Healthy weight

3.6.5.1. Characteristics of analyses. Indicators of healthy weight included continuous measures of body composition (e.g. body mass index [BMI] or waist-to-height ratio) ($n = 34$), or binary indicators of obesity and overweight, typically defined as BMI z-score $\geq$ 85th percentile ($n = 20$) and obesity, defined as BMI z-score $\geq$ 95th percentile ($n = 12$). We identified 66 analyses from 17 observational studies. Most studies investigated availability of ($n = 63$) or interaction with ($n = 3$) residential greenery and more infrequently institutional greenery ($n = 2$, surrounding institution $n = 1$).

3.6.5.2. Synthesis. Across the analyses, 21.9% reported associations with improvements in continuous body composition measures ($n = 32$, <6: 0%, >6: 31.8%), 35% with obesity or overweight ($n = 20$, <6: 18.2%, >6: 71.4%), and 33.3% with obesity ($n = 12$, <6: 1:3, >6: 33.3%). Interestingly, analyses focusing on children over the age of six seemed to more frequently suggest positive associations across the three body composition measures compared to the under six age group, with almost three out of four analyses indicating inverse associations with obesity or overweight. We did not observe any patterns in findings across buffer sizes. Stratification by type of nature contact and context of exposure was not viable due to small variation in these categories.

3.6.5.3. Stratification. Stratification by residential density (e.g. Liu et al., 2007), parental educational attainment (e.g. Schalkwijk et al., 2018; van der Zwaard et al., 2018), and child sex (e.g. Lovasi et al., 2013; van der Zwaard et al., 2018) in some cases revealed differential associations, but patterns were not consistent across green space indicators within studies or across studies.

3.6.6. Stress

3.6.6.1. Characteristics of analyses. We identified 24 analyses from five experimental and four observational studies. Analyses ($n = 17$) from the observational studies predominantly investigated associations with availability of greenery ($n = 13$) of which most was residential ($n = 12$). Experimental studies exclusively investigated nature interaction in the context of the school; that is, in the form of forest school versus teaching as usual (e.g. Roe and Aspinall, 2011) or horticultural activities in school (e.g. Lee et al., 2018). Most of these analyses ($n = 23$) included children over the age of six.

3.6.6.2. Synthesis. Amongst observational studies, one study indicated no significant association between greenery and acute psychophysiological stress, 25% indicated positive associations with cumulative psychophysiological stress ($n = 12$), and one of two with self-reported indices of stress. We could not compare proportions by buffer sizes due to the small number of analyses within different nature buffers.

Across eight experimental analyses, three of four indicated positive associations with acute psychophysiological stress. None of the four self-reported indices, relating to domain specific experience of stress, were statistically significant. No experimental studies investigated cumulative psychophysiological stress.

3.6.6.3. Stratification. Stratification by urban and rural locality of residence revealed that neither systolic or diastolic blood pressure, used to indicate cumulative stress levels (Markevych et al., 2014a), were associated with green space for children residing in rural areas, whereas diastolic blood pressure was consistently lowered and systolic blood pressure only within some spatial buffers amongst city-children. However, since blood pressure is regulated in response to a variety of circulatory inputs, as well as autonomic and hormonal responses to psychological stress, the sensitivity of the measure as an index of stress is questionable (Mygind et al., 2019b).

3.6.7. Mood

3.6.7.1. Characteristics of analyses. We identified three experimental studies and two observational studies, one of which included 32 analyses. These studies evaluated generic self-reports of generic mood, as well as specific feelings, e.g. happiness or anger. Analyses from the observational studies investigated associations with residential greenery ($n = 32$) or interaction with greenery during school ($n = 2$). Experimental studies investigated impacts of participating in an outdoor classroom versus teaching as usual (Largo-Wight et al., 2018), activities at a care farm versus a quiet neighbourhood (van den Berg and van den Berg, 2011), and installing green walls in a classroom versus classrooms as usual van den Berg et al., 2016). Study populations were above six years old. One study included children diagnosed with ADHD aged 9–17 (van den Berg and van den Berg, 2011). This study was included from a pragmatic perspective being difficult to recruit.

3.6.7.2. Synthesis. Across analyses derived from observational studies, 47.1% ($n = 34$) indicated positive associations between availability of green space and mood. No analyses from experimental studies indicated positive effects of green space and mood.

3.6.7.3. Stratification. Greenery associated with total negative emotions, sadness, and feelings of anxiety within four of eight buffers, and happiness in two of eight buffers (Van Aart et al., 2018). Only buffers within the neighbourhood category (buffers of 1000 m or larger) were associated with either of the mood variables. Further stratification was not possible.

3.6.8. Physical wellbeing

3.6.8.1. Characteristics of analyses. Seven analyses from four observational studies as well as one analysis from an experimental study was identified. Analyses from observational studies investigated the availability of residential ($n = 4$) and school ($n = 2$) greenery. One study investigated interaction with nature in location unspecified greenery. The experimental study investigated the impact of installing green walls in a classroom versus classrooms as usual (van den Berg et al., 2016). Four analyses included children under the age of six, one analysis children both over and under six years, and three only children over six years.

3.6.8.2. Synthesis. Across experimental and observational analyses, 12.5% indicated positive associations with generic physical wellbeing indexes ($n = 8$). Due to the limited number of analyses, we did not perform subgroup analyses.

3.6.8.3. Stratification. Stratification by urban or rural location of residence suggested an associated with improved physical wellbeing within the urban subgroup, but not the rurally residing children amongst for three of four exposures (Tillmann et al., 2018a).

3.6.9. Motor skills

3.6.9.1. Characteristics of analyses. Two experimental and two observational studies covering a total of eight exposures were identified. Observational studies investigated availability of residential green space. Experimental studies investigated continuous outdoor education program compared to children in two traditional nurseries (Monti et al., 2019) and spending time in a natural area versus built outdoor kindergarten area (Fjørtoft, 2004). Most analyses included children under the age of six (81.3%, $n = 16$).

3.6.9.2. Synthesis. Across two observational studies (including three analyses each), 66.6% ($n = 6$) of the analyses suggested that greenery was associated with better generic fine and gross motor skill scores. These results were consistent across three green space buffers in the intermediate and neighbourhood range (Liao et al., 2019).

Based on the experimental studies, 60% ($n = 10$) of the analyses suggested improvements in gross motor skills.

3.6.9.3. Stratification. No immediate age-related patterns were apparent. Further stratification was not possible.

3.6.10. Language and communication skills

3.6.10.1. Characteristics of analyses. We identified four studies, of which two were experimental and two were observational, covering four exposures. Various aspects of language development, e.g. lexical and grammatical diversity in speech, were investigated. The observational studies investigated residential greenery ($n = 3$) or interaction with greenery at school ($n = 1$). The experimental studies considered impacts of ecotherapy (Kalashnikova et al., 2016) and exercises in a natural versus indoor environment (Cameron-Faulkner et al., 2018). Children were predominantly under six years of age (75%, $n = 12$).

3.6.10.2. Narrative synthesis. Dynamically measured total lexical diversity was numerically higher for three out of four neurotypical children during time spent in a natural environment versus an indoor classroom or outdoor classroom (Richardson et al., 2018). Furthermore, Cameron-Faulkner et al. (2018) found that the quality of parent-child communication, operationalised as the number of utterances and coherent conversation, was superior in the natural environment. Lastly, language development deficits were associated with proportion of natural area within sub-district of residence, but not per capita natural area, nor proportions for inhabitants living with no more than 300 m from a natural area (Kabisch et al., 2016). These analyses were based on bivariate analyses and included no control for confounding factors.

Based on the experimental studies, lexical and grammatical diversity was found to be improved amongst children with speech disturbances following so-called ecotherapy (Kalashnikova et al., 2016), but not among neurotypical children during exercises in a natural versus indoor environment (Cameron-Faulkner et al., 2018).

3.6.10.3. Stratification. No apparent age-related patterns were observed. Further stratification was not possible.

3.6.11. Birth outcomes

3.6.11.1. Results from previous meta-analyses. Previous systematic reviews (Banay et al., 2017; Woods et al., 2017) and a meta-analysis (Dzhambov et al., 2014) covered research, much of which overlapped, dating up to 2016. Dzhambov et al. (2014) suggested a very small positive association between immediate (i.e. 100 m from home) residential greenery and birth weight (BW) (pooled correlation coefficient: 0.049 [95% CI: 0.039, 0.059], pooled standardized regression coefficient: 0.001 [95% CI: −0.001, 0.003]). Considering the vast amount of unexplained heterogeneity across the studies (correlation: $I^2 = 99.70$, standardised regression: $I^2 = 91.05$), results should be interpreted with caution. The authors discussed the possibility of subgroup differences in associations (e.g. per maternal educational attainment). They also ventured that green space measurement weaknesses and variations in control variables (e.g. inclusion of noise and air pollution) played an important role (Dzhambov et al., 2014). Studies investigating green space in intermediate (i.e. between 100 and 500 m) and neighbourhood (i.e. 500 m or more) distances from maternal residency more often reported positive associations and larger effect sizes, although these buffers were less frequently investigated (Dzhambov et al., 2014; Woods et al., 2017).

3.6.11.2. Synthesis. A number of studies ($n = 13$), including a vast number of exposures ($n = 125$, ranging from 1 to 34 exposures from non-stratified analyses in the individual studies), have been published after 2016. Across analyses, ≈20% indicated a positive association between availability of residential green space at any buffer and continuous measures of BW ($n = 30$) and term BW ($n = 59$), 52.5% with reductions in risk of low BW ($n = 30$), 6.3% with reductions in risk of very low BW ($n = 32$), 23.8% with reductions in risk of term low BW ($n = 32$), 9% with reduced risk of being born small for gestational age (SGA) ($n = 67$), 11.8% with risk of preterm birth (PB) ($n = 68$), and 21.9% with risk of very PB ($n = 32$).

3.6.11.3. Stratification. Associations between green space and BW were observed more frequently in more densely populated areas (Eriksson et al., 2019; Fong et al., 2018) and areas with more pollution, irrespective of population density (Dzhambov et al., 2019). This seems to agree with previous interpretations that differential control for pollution variables may contribute to observed heterogeneity in pooled estimates (Dzhambov et al., 2014). In conjunction with this perspective, Laurent et al. (2019) found that air pollution mediated, rather than moderated, the association between green space and risk of low BW; as such, specifying models to test associations between green space and birth outcomes, without including or stratifying by air pollution levels, may underestimate the actual correlation. When adjusting for the totality of urban exposures, including built environment, air pollution, road traffic noise, meteorology, and road traffic factors, green space, operationalised as NDVI in a 100 m buffer around maternal residency, was identified as the most consistently occurring exposure to correlate with term low BW (Nieuwenhuijsen et al., 2019).

In contrast to previous reviews, we did not observe a larger proportion of positive findings across birth outcomes in the larger buffers in these analyses. In some studies, stratification by maternal education provided differential results (e.g. Fong et al., 2018), while no such mechanisms were observed elsewhere (e.g. Glazer et al., 2018; Richardson et al., 2018). Stratification by socioeconomic factors, such as household income (Fong et al., 2018) or area-level deprivation (Abelt and McLafferty, 2017), and groups defined by race (Fong et al., 2018; Glazer et al., 2018; Laurent et al., 2019) likewise provided differential results for some birth outcomes and greenery buffers, but not for others. Two studies utilised longitudinal assessments to investigate if distinct periods during pregnancy were more responsive to green space exposure than others, but no consistent trimester-specific patterns were observed across the studies (Agay-Shay et al., 2019; Cusack et al., 2017).

3.6.12. Allergy

3.6.12.1. Results from previous meta-analyses. One previous systematic review and meta-analysis (Lambert et al., 2017) covered research dating up to 2017. The authors reported that heterogeneity of outcomes and exposures, as well as the small number of studies investigating residential greenness and allergic respiratory disease, limited the authority of the meta-analyses. Pooled odds ratios across six studies did not indicate an association for allergic rhinitis (OR: 0.99 95% CI 0.87, 1.12, I^2: 72.9). Considering the vast amount of unexplained heterogeneity across the studies as well as variation in exposure and outcome measurement tools, results should be interpreted with caution. Furthermore, few of these studies included air pollution measures, which must be expected to interact with allergic symptoms.

3.6.12.2. Narrative synthesis. Subsequently published studies provide similar results, with the majority finding no positive or negative associations with allergic rhinitis or generalised allergic symptoms, irrespective of green space measures or buffers (Boeyen et al., 2017; Cilluffo et al., 2018; Gernes et al., 2019; Tischer et al., 2017). One study suggested reductions in pulmonary symptoms were associated with residential levels of vegetation, measured via NDVI in a 200 m buffer (Cilluffo et al., 2018).

3.6.13. Asthma

3.6.13.1. Results from previous meta-analyses. In the aforementioned meta-analysis by Lambert et al. (2017), no significant associations between green space and asthma were identified, as indicated by the pooled odds ratios (OR: 1.01 95% CI 0.93, 1.09) and substantial heterogeneity (I^2: 68.1%). In a recent systematic review (Hartley et al., 2020), which covers more recent research and adds to the meta-analysis (Lambert et al., 2017), the same observation was made. Consequently, Hartley et al. (2020) concluded that there appears to be no direct association between green space and asthma in children, but that it is likely that green space modulates associations with other exposures, such as pollutants. However, considering the vast amount of unexplained heterogeneity across the studies, as well variation in exposure and outcome measurement tools (Lambert et al., 2017), results should be interpreted with caution. As was the case for allergic symptoms, very few studies controlled for or stratified analyses by air pollution measures, which must be expected to interact with asthma.

4. Discussion

4.1. Summary of evidence

4.1.1. Natural landscapes and socioemotional function and development in children

In this systematic review, we assessed the consistency with which elements of child socioemotional function and development was associated with and was influenced by natural environments and features. Based on the consistency observed across the body of literature, the evidence for positive benefits of natural environments appears somewhat scattered; associations were found with children's ability to form positive relationships (25.0%, $n = 48$ unstratified analyses), socially adaptive behaviours (17.1%, $n = 105$), social competences (50.0%, $n = 8$), emotion management and expression (13.9%, $n = 79$), behavioural inhibition (26.8%, $n = 71$), thoughts of self (33.3%, $n = 6$), overall socioemotional adaptation (35.1%, $n = 37$), and Autism Spectrum (40%, $n = 5$) and Attention-Deficit/Hyperactivity disorder prevalence or symptomology (55.0%, $n = 20$).

Certain patterns seemed to transcend the body of the literature providing some nuance to these summary proportions. In particular, the use of context-bound indices provided a higher proportion of positive findings compared to generic indices. This might suggest that while there is an immediate relationship between interaction with nature and, for example, emotion management and expression, this does not translate to more generic patterns of emotion management and expression. It may also indicate that contextually bound indices are more sensitive and able to detect a true relationship. However, most of the contextually bound indices were developed by the authors for the specific projects and were considered to involve a probable risk of bias (see Section 3.3). Finally, this may suggest that the likelihood of identifying a true relationship is higher when investigating time spent in green space with the mere availability of vegetation around the home or educational institution. As results from the experimental research were more consistently improved than results from observational research, which was dominated by availability-type assessments, this would seem likely. However, the experimental research, and the studies using context-bound indices, are currently largely based on non-randomised designs assessed to involve some or serious risk of bias. Therefore, it is at present difficult to disentangle the possibility of these various explanations.

There are indications that the availability of greenery is more likely to associate with aspects of socioemotional function under specific circumstances; across most of the socioemotional domains, the exclusive focus on analyses including urban samples increased the likelihood of positive findings. Furthermore, subcultural differences pertaining to, for example, ethnic or cultural capital groupings, may influence the likelihood of using exterior green spaces and therefore mediate links between availability of green space and socioemotional outcomes. Sex was in some instances found to mediate the association with either boys or girls seeming to attain benefits from having access to nature. It seems probable that the true extent of the importance of these social factors, and their intersecting dynamics, have previously been overlooked; while the importance of these factors is generally appreciated in the form of statistical control towards the end of identifying an association in spite of confounding from social and cultural contexts, it seems that the more appropriate approach would be to treat these factors as mediating conditions that allow or disallow associations to occur. It appears that it is not *in spite* of maternal education or ethnicity that the availability of green space allows children to grow into resilient beings, it is *because of* these factors. We appreciate that this suggestion may appear rather (socio-culturally) deterministic. It is likely that the two scenarios coincide, but we propose that further practicing the idea of sociocultural factors allowing or disallowing use of natural environments will bring forth more clarity and consistency in findings.

4.1.2. Proximal outcomes as bidirectional pathways to socioemotional development

We have reviewed and, where possible, synthesised the existent research pertaining to child states and behaviours that may associate with or causally influence socioemotional function and development. Most of the research, however, utilises designs that are only suited for correlational inference.

On the basis of the consistency of positive findings across the literature, domains within the cognitive domain must be considered central in spite of a smaller evidence based compared to other proximal outcomes. Green space was consistently associated with some of the cognitive domains, particularly the working memory domain where the experimental and observational research converged (both proportions >70%), and is in line with other reviews (Ohly et al., 2016; Stevenson et al., 2018). The tasks within this domain involved remembering sequences of stimuli and subsequently performing mental modulations of this information. While these tasks are thought to reflect working memory, they also rely on the child's capacity for directed and sustained attention. Despite the theoretically-driven relevance of attention, the findings from purer measures of high-order attention, the findings from purer measures of high-order attention were markedly less consistent, which also coincides with previous reviews (Stevenson et al., 2018). Considering the importance of working memory for the capacity to attend to social and emotional cues in self and others (McQuade et al., 2013), this is a likely core, bidirectional pathway to socioemotional child development. From a neurological perspective, this is underpinned by the delicate intertwinement between higher-order and social cognitive brain circuitry (Koban and Pourtois, 2014).

Although based on a limited and largely descriptive evidence base, play behaviours may also be a core pathway. There is some inconsistency between studies relating to associations between naturalised playgrounds or natural features and sociodramatic types of play, which is likely an artefact of variable operationalisation and measurement. The conceptual and theoretical complexity concerning the phenomenon of play challenges operationalisation and quantitative measurement of play (for discussion, see Zosh et al., 2018). We identified, however, some pioneering studies investigating aspects of free play and natural environmental features. The more recent studies, which have explored not only incidences of types of play but also the longevity of play, suggest that children in naturalised playgrounds tend to engage in one type of play for longer durations of time. Although we appreciate that this could be interpreted in more than one way, we suspect that this may be an indication of more deeply engaged play. This could be a by-product of enhanced cognitive functioning, as the above paragraph would suggest, or of features of nature that invite prolonged and engaged play (e.g. intrinsic fascination or functional diversity, rich opportunity for use, and continuous challenge; Chawla, 2015).

Another notable proximal outcome concerns associations between green space and risk reduction for overweight and obesity amongst children over the age of six, but effects are less consistently seen for continuous body composition measures and obesity alone. For children under six, body composition measures generally did not seem to associate with availability of greenery. For children over the age of six, green space may thus act as a buffer against overweight and obesity (proportion >70%) and thereby also the associated social stigma (Pizzi and Vroman, 2013).

Across the body of observational and experimental evidence, associations between green space and movement behaviours appeared mixed. Based on a small body of evidence, experimental studies frequently reported higher levels of MVPA, VPA, and MPA during green experimental conditions compared to control conditions. In comparison, the proportion of positive results in the more numerous observational studies investigating linkages between various green space indicators and the same measures did not exceed 50% for any movement behaviour outcome across home, residential, school, and unspecified locations. This may suggest that the context and type of activity in question plays an important role, which would explain the higher prevalence of positive findings amongst the experimental studies that typically investigate the influence of a single type of activity within a more controlled setup. It may also indicate that when positioned within the context of everyday life and the sum of activities and exposures, the contribution of green space as a place for PA is reduced. Indicatively, Wheeler et al. (2010) found that children spent 13% of their time outdoors and 2% of their time in green space. This may suggest that when children spend time in green space, as would be indicated in the experimental studies, they accrue more PA, but because they don't spend time in green space, the mere availability of such does not consistently associate with more PA, as indicated by the observational studies.

Physical inactivity is known to be an important predictor of obesity, albeit second to diet (Davies, 2019). Although the possibility of an association between green space and movement behaviours remains, it seems likely that other pathways may be involved with the risk of development of overweight or obesity. Overweight and obesity is a hugely complex phenomenon caused by a multitude of interacting genetic, social, and environmental factors, but within the scope of factors relevant to this review, we suggest that the cognitive and socioemotional precursors may be the most influential factors. However, we identified no studies exploring associations between availability of green space with adherence to daily movement guidelines. A more holistic view on movement behaviours may provide a more succinct characterisation of a core pathway between green space and socioemotional function and development, as well as health outcomes broadly speaking. Insufficient sleep, for example, predicts childhood obesity (Poorolajal et al., 2020). Due to the heterogeneity of types of green space and the broad set of potential uses, green space may not associate consistently with one type of movement behaviour, but it may at a general level encourage healthier holistic daily movement behaviours. This would be a valuable perspective to pursue in future research.

The evidence supporting associations between green space and motor skills, language, and communication skills is presently small, and results are tentative. Nevertheless, the research within these domains tends to more often suggest positive associations between interaction with and availability of green space and motor skills, language, and quality of parent-child communication. The development of the motor system, which is responsible for motor skills and preparation and execution of bodily movement, is increasingly seen as a precursor to language and socioemotional development, as independent locomotion and refined object manipulation allow the child to gain knowledge of the external world and increase self-awareness (Iverson, 2010). Although the evidence for an association between green space and motor skills, language, and communication skills is currently weak, this could be a promising pathway to explore further.

We found little evidence for positive associations between green space and mood, physical wellbeing, stress, and screen time. Within some of these domains, detection bias may confound real relationships. In regard to mood, it is likely that the specific activity in which the children participated, in conjunction with the exposure, played a role. Mood may also lend itself poorly to questionnaire-based measurement when considering the high temporal variability in states, depending on personality type, as well as social desirability bias. Similar issues pertain to self-report of stress, and some of the challenges involved with psychophysiological measurement of stress are discussed in depth elsewhere (Mygind et al., 2019b). Screen time was based on parent-report, which is likewise susceptible to social desirability bias, and most frequently measured in terms of duration of screen time, without attention to the type of electronic device used and the content of the screen time. These factors have been suggested to play a role, as has the broader social context during screen time (e.g. whether the child watched TV alone or with a friend; Bickham and Rich, 2006). Lastly, physical wellbeing was associated with green space for urban but not rurally residing children (Tillmann et al., 2018a), which could suggest that non-stratified analyses of both urban and rural populations would confound an actual relationship. The mixed findings within these domains may therefore be caused by measurement difficulties rather than actual absence of correlation.

There is little evidence for direct associations between availability of green space and asthma and allergy prevalence. However, it seems likely that green space interacts with other elements of the child exposome (e.g. air pollution) which might associate with asthma and allergy prevalence. Likewise, green space appears to be associated with birth outcomes via interactions with other environmental exposures. On the basis of these interpretations, we hypothesise that green space is associated with these outcomes in the presence of detrimental environmental factors, but not in the absence of these, as will more often be the case in rural settings. A slightly bold interpretation will thus be that for children (from conception to age 12) who are exposed to air pollution, green space may slightly reduce risk of adverse birth outcomes, allergy, and asthma.

4.2. *Strengths and limitations*

4.2.1. *Within studies*

Common sources of risk of bias in SDO studies were reported in

Section 3.5. We identified few studies without either probable or severe risk of bias in at least one item. Improved study quality may therefore result in different results. Some additional considerations should be made.

While most observational studies controlled for important confounding factors (see Section 3.5), there was considerable heterogeneity in terms of the rigour with which control was made and the assessment methods. This was perhaps most plainly exemplified in a double-publication using the same dataset, sample, exposures, and outcomes where a difference in results (the main effect of green space on boys weight status indicators non-significant rather than negative) was seemingly due an introduction of a squared and quadratic age-factor (Sanders et al., 2015a, 2015b). Some studies used systematic approaches through which confounding factors are identified, e.g. pre-determining variables or backwards elimination (e.g. Madzia et al., 2019; Zach et al., 2016), but most often the choices were not clearly reported. Naturally, this variation may be expected to contribute to some of the inconsistency in the derived findings considering the importance of sociocultural factors as discussed in Section 4.1.1. Although stratification of the evidence did not reveal factors that consistently interact with or obscure potential associations between nature exposure and SDOs and P-SDOs, the identified factors should be further examined, or at least included in sensitivity analyses, in future research.

In Section 3.5, we discussed some observed issues pertaining to statistical modelling in clustered samples and the absence of adjustment for multiple testing. Statistical fitting of the relationship between exposures and outcomes was performed in a number of ways; some studies compared NDVI tertiles or quartiles (e.g. Donovan et al., 2019) whereas most used linear forms of modelling (e.g. Madzia et al., 2019). Interestingly, in regards to birth outcomes, Fong et al. (2018) found that the association was best described in a nonlinear fashion. Specifically, term BW (TBW) was found to associate with NDVI between 0.25 and 0.5 suggesting a large difference (a 6.69% increase per 0.1 NDVI unit, approx. 20 g). Below 0.25 and above 0.75, no difference was discerned. Although there are no distinct boundaries for different types of land cover, negative values typically reflect water surfaces, values around zero little or no healthy vegetation, and values close to one dense vegetation. Values between zero and 0.25 would thus indicate no or sparse vegetation and anything above 0.75 healthy dense to very healthy and dense vegetation. Increases in NDVI within these spectra were not found to be associated with TBW. It is speculative whether this will translate to socioemotional outcomes, but it may suggest that linear fitting is not the most appropriate statistical approach.

4.2.2. *Within review*

Our analyses are based on a conservative summary of the existing findings, that is, every exposure and every indicator is counted separately and subsequently summed with similar indicators. Elsewhere, analyses are performed at the study level and based on evaluations of the overall evidence. For example, Lachowycz and Jones (2011) categorised studies as presenting either evidence for a positive, equivocal (weak or mixed evidence), no relationship, or negative association between green space and PA and weight-related indices, respectively. Previously, we have used a similar approach in which we applied a mixed categorisation for instances where more than one indicator per outcome was used and were found to be divergent (Mygind et al., 2019a) to assess the experimental evidence for health promoting benefits of immersive nature experiences.

In this study, we elected to perform the analyses at a finer level still, as some studies included vast numbers of exposures as well as indicators. We found that it was not unusual for studies to include ten or more comparisons and that some studies included more than 30 individual comparisons, when considering all distinct exposures and buffer sizes (e.g. Cusack et al., 2017; Van Aart et al., 2018) and interaction and stratification models (e.g. Sanders et al., 2015b). Without clear confirmatory hypothesis testing and transparent reporting, as well as appropriate statistical adjustment for multiple comparisons, large numbers of comparisons introduce a risk of increasing and understating false positives. It is possible that findings from such studies could rightly be categorised as providing equivocal (mixed or weak) evidence for an association, but this does not convey the full extent of the ambiguity from which these finding is extracted. For example, if term birth weight associates with the proportion of tree canopy coverage within a radius of 1000 m from home, but not at radii of 50, 250 or 500 m (Cusack et al., 2017), this could be taken for weak evidence, but as the finding appeared amongst ~30 other comparisons, it is likely to be a false positive and, as such, provide no evidence in either direction. As such, it would be misleading to index this as an indication, even a weak one, for an association. Considering the profound overlap between these exposures, that is, all of these buffers would be nested within the 1000 m buffer, surely the findings, if indicative of a strong and consistent association, should display more convergence. Cusack et al. (2017) clearly disclosed that findings across exposures in adjusted models were inconsistent and called for further attention to confounding and modifying factors, but such commendable reporting is not consistently performed and may lead to biased interpretations across the literature. While our summary could be criticised for being overly conservative, we maintain that this is required to provide a realistic status-quo displaying the current ambiguity within the research, meanwhile remembering that stratification, in particular according to age and residential density (in particular living in cities versus rurally), and for some outcomes also sex, seems to provide more consistent patterns. Our syntheses would have been stronger had we been able to systematically factor in effect sizes and study quality. Unfortunately, effect sizes were not consistently reported, and the risk of bias assessments suggested that most studies involved moderate or high risk of bias resulting in few studies from which to perform restricted analyses.

While the vote-count approach is a helpful sanity check to estimate consistency across a large, heterogenous number of studies, it is based on considerable data resolution reduction, from variation at the level of participants to the level of association or no association between unique exposures and outcomes. Furthermore, the counts are ultimately reliant on individual study design and quality, as well as sample sizes. Applied to relationships which are difficult to observe, e.g. associations or effects of small effect sizes or only that are present only under certain circumstances, and therefore requires highly sensitive measurement and a large sample, the vote-count approach might suggest very low consistency of research and the absence of association when in fact these may simply be hard to find. As such, low consistency scores shouldn't be interpreted as evidence for a lack of association; it should, however, be interpreted as evidence for either no association or the existence of a subtle or circumstantial association. For meta-analyses to become possible sooner rather than later, replication studies or, as a minimum, use of exposure and outcome measures that are consistent with existing research is required. As the research base grows and more high-quality and comparable studies are published, actual pooling of effect sizes and calculation of confidence interventions will become meaningful and feasible. This will be an important step towards identifying and estimating relationships and effects.

We appreciate the complexity and potential controversy around these SDO domains applied within this review. Albeit both overlapping and interdependent, they provide information concerning socioemotional function at different levels, that is, at levels of relationships, behaviours, and competencies. Relational success with adults or peers relies on appropriate behavioural inhibition, amongst a host of other factors, for example social cognition and situational awareness which could, however, also be interpreted as indicators of behavioural inhibition, in their effects. This was, for example, the approach taken by Weeland et al. (2019) who synthesised a range of relational, behavioural, and competence-oriented measures to quantify cognitive, behavioural, and affective aspects of self-regulation. Although this provides an appealing interpretational simplicity, it disregards the subtleties of socioemotional growth and possibly levels out or exaggerates, depending on the outcome, associations with green space. Although imperfect, the categorisations used within the current review maintains distinctions between important socioemotional growth factors. In the future, finer detail and increased confidence in the results will be allowed by the accumulation of studies and, hopefully, replication studies.

It is necessary to emphasize that the mechanistic model is not a representation of directly investigated linear and mediatory relationships. This has several implications that should be considered when interpreting the model. In particular, we do not know which of the suggested pathways are the most important, or will even remain significant, when considering the coexistence of more of these pathways in real-life. The model only suggests a likelihood of a relationship between these outcomes. An additive or even synergistic effect of advances in two or more of the P-SDO's on the SDO's is also possible. Furthermore, there may be P-SDO's unaccounted for in the existing research that are more important than the outcomes included here.

The majority of the research on which the model is based is correlational and does not allow for causal inferences, as the modelling might otherwise suggest. This is the case for many of the nature-P-SDO, P-SDO-SDO and nature-SDO relationships alike. Exceptions include the BW-SDO pathway which from a temporal perspective eliminates the possibility that childhood SDO might influence BW. It is possible that an oscillatory or spiralling model, indicating an iterative, mutual interdependency, or a ladder model, representing a process whereby reaching developmental milestones in one outcome enables growth in the other, which then enables growth in the first developmental area and so forth, would have been more appropriate. It is even possible that individual pathways work through distinct modes of interdependency and growth. For the purposes of this review and ease of interpretation, we have illustrated the findings in this more linear fashion.

While SDO's and P-SDO's engaged in bidirectional relationships, many of the P-SDO's are also known to engage in interdependencies, e.g. physical activity influences cognitive function (Biddle et al., 2019) and motor skills relate to language development (Iverson, 2010). Thus, this mosaic could arguably be interpreted as a mechanistic model where individual or multiple P-SDO's present mechanisms and SDO's outcomes, or vice versa. In other words, the implications of the model may transcend those of child socioemotional function and development. The model can aid our understanding of how these mechanisms interact to form the trajectories of holistic child development related to contact with or access to nature and guide further research into these mechanisms. It should be emphasised, however, that the summaries pertaining to the P-SDO's are based on single reviewer extractions of data and have not been subjected to risk of bias assessments. The quality of the evidence for the relationships between contact with nature and the P-SDO's was thus not systematically examined and data extraction errors otherwise identified via reviewer triangulation would not have been eradicated. However, the use of highly manualised data extraction approaches, as well as a consistent vote count synthesis approach, reduce the risk of errors and bias that would affect data syntheses in a systematic manner.

5. Conclusions and future directions

5.1. Do natural landscapes facilitate socioemotional development?

We have reviewed the substantial body of literature pertaining to associations with and effects of interaction with and availability of natural environments and child socioemotional function and development. We have found a considerable amount of evidence suggesting positive associations but placed within the context of all the existing research, findings appear inconsistent and study quality is heterogeneous. Furthermore, potential selection, detection, and statistical bias was observed in both observational and experimental studies. Although null findings may not necessarily indicate an absence of an association, they convey information, that within the specific context of the study (e.g. population, exposure, measurement of the exposure, outcome, and measurement of outcome), no evidence for a positive association or effect was identified. Not appreciating the importance of these high percentages of null findings would lead to incomplete conclusions and, far more dangerously, inadequate recommendations for policy and practice. The empirical evidence for benefits of availability of and interaction green space for child socioemotional function and development must currently be considered limited.

The inconsistency in the findings when addressed at an outcome level across studies has previously been observed in systematic reviews considering subsets of the research covered within the present systematic review (Mygind et al., 2019a; Tillmann et al., 2018b). Across both observational and experimental studies, Tillmann et al. (2018) found that approximately half of all the reported findings indicated significant improvements to child and adolescent mental health and the other half no significant differences. Mygind et al. (2019) found that across physical, social, and mental health, only 60% of outcomes were found to be improved following interventions involving direct interaction with nature compared with control conditions. The remaining 40% were either non-significant or mixed; that is, studies using more than one measure per outcome found that some measures were improved and others not. Non-significant findings were seldom discussed, and mixed findings were mostly reported as an indication of a positive finding, disregarding that individual measures operationalised to quantify the same phenomenon were not uniformly influenced, thereby understating the ambiguity of the findings (Mygind et al., 2019a). We add to these reviews by providing an overview which also addresses findings at the level of individual exposures, allowing for finer analyses of the parameters contributing to the inconsistency.

In this review, we have identified a number of potential mediating and moderating factors. Associations were more frequent in urban samples and samples including children with psychological disorders (as indicated by investigations into use of nature for treatment and ADHD prevalence and symptoms). In some cases, sex and socioeconomic and cultural background mediated associations. Finally, green space in schools more often associated with the socioemotional outcomes compared to residential greenery. However, more work is needed to establish the mediating and moderating conditions.

5.2. The makings of a mechanistic mosaic

Proximal child states and behaviours were likewise reviewed. Interestingly, we found very few existing reviews that comprehensively covered the exposures and interventions included in the current review. For example, while previous studies have summarised subsets of the literature pertaining to green and public open space and physical activity (Ding et al., 2011; Lachowycz and Jones, 2011; McCrorie et al., 2014) and healthy weight (Carter and Dubois, 2010; Lachowycz and Jones, 2011) amongst child populations, we did not identify any comprehensive, contemporary reviews focusing explicitly on green space (rather than, for instance, a mix of green and public open spaces such as athletic fields). Thus, the present publication provides the first comprehensive review to summarise observational and experimental research investigating associations between natural environments and childhood cognition, play, movement behaviours, screen time, healthy weight, stress, mood, physical wellbeing, motor skills, and language and communication skills. Furthermore, we were able to supplement findings from the most recent research to existing meta-analyses pertaining to birth outcomes, allergy, and asthma. It should be reiterated, however, that this research was not submitted to quality assessments. The summary metrics are therefore based on studies of heterogenous quality. Databases and codebooks are available in the OSF repository (https://osf.io/fs5m7/?view_only=b833ff48f2314d43b12c3af7a1ea1be8).

With the exemption of birth outcomes, all of these must be expected to engage in a bidirectional relationship with child socioemotional factors. The cognitive domain variables and overweight (for children over the age of six) appeared as the proximal outcomes most consistently associated with interactions with and availability of natural spaces. Although based on a limited and largely descriptive evidence base, play behaviours may also be a core pathway, in particular considering the converging observations suggesting that children engage in play behaviours for longer periods of time when in natural environments. The evidence for associations between green space and movement behaviours was mixed when assessed across experimental and observational studies. We propose that an increased holistic focus on movement behaviours, that is, an approach that considers the balance between physical activity, as well as sedentary time and sleep, and not merely as distinct behaviours, would more accurately portray the association with green space due to the diversity of uses afforded within natural environments. The evidence supporting associations between green space and motor skills, language, and communication skills was found to be small and results were tentative. Although the evidence for an association between green space and motor skills, language, and communication skills is currently weak, these could be promising pathways to explore further. We found little evidence for positive associations between green space and mood, physical wellbeing, stress, and screen time, although we deem it likely that these findings are confounded by detection bias.

We have discussed sources of the inconsistency observed across both socioemotional and proximal indicators. On the basis of findings derived from stratified analyses, we discussed the importance of sociocultural factors, not only as noise to be controlled for, but a barrier or facilitator which permits or prohibits children in using available green space. Indicatively, the range within children roam freely and independently has changed over time and differs between countries suggestive of cultural change and diversity (Kyttä et al., 2015). Likewise, risk adversity amongst parents and ECEC practitioners, for example, has been found to differ by country (Sandseter et al., 2020), but also amongst socioeconomic groups (Veitch et al., 2006). Nevertheless, greater park greenness (parks within the 75th percentile for greenness) was associated three times the odds of using the park compared with the least (within the 25th percentile) amongst American teenagers after controlling for age, sex, race/ethnicity, and household income (Dunton et al., 2014). As such, while availability of green space does not guarantee green space interaction, it seems to increase the likelihood of use and thereby possible benefits.

In analyses seeking to identify the most important factors influencing, e.g., child obesity (Ortega Hinojosa et al., 2018) or BW (Nieuwenhuijsen et al., 2019) from a comprehensive list of social and physical environment variables, social factors explain by far more of the variation than any physical environment variable. Although NDVI in these studies rates higher than other physical environment variables, it remains that sociocultural factors, such as percentage English learners, socioeconomic disadvantage, or presence of credentialed teachers (Ortega Hinojosa et al., 2018), have a stronger bearing on healthy child development. In other words, within the socioecological totality of a child's world, green space may play a role, but sociocultural factors will be decidedly more important. While these small effects for the individual may provide both large and important benefits at the population level, due to green space being widely accessible and modifiable, it is important to recall the hierarchy of factors that influence a child's holistic development. Social factors play a ubiquitous role in child development, and the relationship between these factors, availability of nature, use of nature, and the potential derived benefits, require further attention in future research.

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CRediT authorship contribution statement

Lærke Mygind: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization, Project administration. **Mette Kurtzhals:** Investigation. **Clare Nowell:** Investigation. **Paulina S. Melby:** Investigation. **Matt P. Stevenson:** Investigation, Writing - review & editing. **Mark Nieuwenhuijsen:** Writing - review & editing. **Jarrad A.G. Lum:** Writing - review & editing. **Trine Flensborg-Madsen:** Writing - review & editing. **Peter Bentsen:** Writing - review & editing. **Peter G. Enticott:** Conceptualization, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2020.106238.

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