Nature-based early childhood education and children's physical activity, sedentary behaviour, motor competence and other physical health outcomes: a mixed-methods systematic review

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Abstract

Background: The purpose of this review was to synthesise global evidence on the association between nature-based ECE and children's physical activity (PA) and motor competence (MC).

Methods: A literature search including nine databases and grey literature was in August 2020. Studies were eligible if a) children were aged 2-7 years old and attending ECE, b) ECE settings integrated nature, and c) they assessed child-level physical outcomes. Two reviewers independently screened full-text articles and assessed study quality. Data extraction was completed by one reviewer and checked by another. Synthesis was conducted using effect direction (quantitative) and thematic analysis (qualitative), and combined using a results-based convergent synthesis.

Results: 1,370 full text articles were screened and 39 unique (31 quantitative; 8 qualitative) studies were eligible. 20 quantitative studies assessed PA and 6 assessed MC. Findings indicated inconsistent associations between nature-based ECE and children's sedentary time, moderate-to-vigorous PA (MVPA), speed and agility, and object control skills. A positive association was found for balance. Positive associations were also found between specific natural elements (e.g. vegetation) and lower sedentary time, and higher MVPA and total PA. The certainty of evidence was very low across all outcomes. From the qualitative analysis, studies indicated that nature-based ECE affords higher intensity PA and risky play which may explain improvements in some domains of motor competence, however some also suggested that PA and risk was similar irrespective of playground type.

Conclusions: Specific natural elements in ECE settings were associated with higher MVPA and PA but not nature-based ECE per se. The quality of the current evidence makes it difficult for decision makers to inform investment into nature-based ECE for improving children's health outcomes. Robust experimental designs that describe the dose and quality of

nature are needed to inform whether nature-based ECE is better than, or equal to, traditional ECE.

Systematic Review Registration: CRD42019152582

Key Words: Nature; Early childhood education; children; preschool; physical activity; motor competence.

1. Background

Traditional ECE is typically characterised by predominately man-made structures, such as swings, climbing frames and slides in the playground with very few natural features integrated. Children who attend traditional ECE spend only a small amount of their time outdoors providing them with few opportunities to engage in physical activity and play. In comparison, one emerging type of education, nature-based early childhood education (ECE), is characterised by integrating nature into its philosophy and design, and children would typically spend most of the day outdoors engaging with natural elements (1). Key characteristics of the environment may include trees, vegetation, natural loose-parts, rivers or ponds and other natural materials that enable interaction through play. Examples of nature-based ECE include nature-based preschool or kindergarten and forest kindergartens; however nature-based ECE can vary in approach, exposure and how much time children spend outdoors (1). By providing children with more time outdoors in a diverse environment, nature-based ECE may be an important way of increasing children's physical activity levels and developing their motor competence.

It is widely accepted that engaging in regular moderate-to-vigorous physical activity (MVPA) (on average 60 minutes per day) in childhood can promote a range of physical, social, cognitive and emotional benefits; for example, weight management, bone density and mental wellbeing (2-4). However, children are increasingly living more sedentary lives resulting in low and declining levels of physical activity during formal education and rising childhood obesity (5-7). Approximately 41 million infants and young children (0-5 years) are living with overweight or obesity globally (8), and overweight is both a cause and consequence of low physical activity levels (9).

In addition to engaging in regular MVPA, it is also important to participate in different types of physical activities to develop children's motor competence (10-12). Motor competence is the basic skills children should be competent at, such as running, jumping, hopping, throwing, catching and climbing (13). These skills are important because they are associated with increased physical activity levels in childhood and children who engage in higher levels of physical activity tend to have better motor competence (13, 14). However, levels of motor competence are low in preschool and school aged children from high-income countries (15, 16), and this is likely impacting children's current and future physical activity levels as they mature into adolescence and adulthood. Low levels of physical activity and motor competence during early childhood is also likely to impact maintenance of healthy weight status across the lifespan (13, 17). Additionally physical activity, particularly, outdoor play are favourably associated with most sleep outcomes in toddlers and preschool children (9).

If physical activity levels and motor competence are to be improved, intervening in the early years when children are rapidly developing is crucial, and the emergence of nature-based ECE may enhance these outcomes (15, 18). Nature-based ECE provides access to and diversity of features that provides children with multiple affordances to engage in active and outdoor play. Affordances are the opportunities the environment provides and how an individual perceives and interacts with them according to their individual capabilities (19-22). For example, a tree can enable children to climb, run around, or provide shelter. These natural elements may afford opportunities for diversifying play types, developing motor competence and increasing physical activity (23). When children spend time outdoors playing in ECE, approximately 40% of their time is spent engaging in physical activity (24) and some evidence has suggested motor competence may be developed if active play interventions are provided in these settings (25, 26). A recent systematic review explored the associations between exposure to nature (including ECE and non ECE settings) and children's (0-12

114 years) health (27). Based on evidence with a 'likely' or 'high' risk of bias, they found
115 favourable associations on physical activity and weight status and an indication of positive
116 trends for motor competence (27). Similarly, based on weak evidence and a small number of
117 studies, another systematic review indicated some association between nature play and
118 physical activity and motor competence (28).

119 Although previously published systematic reviews have looked at the association of nature
120 more broadly on child and adolescent health outcomes, to our knowledge, no systematic
121 review that focuses specifically on the role of **nature-based ECE** on young children's (2-7
122 years) physical health and development (such as, physical activity, motor competence, sleep,
123 weight status etc.) exists. This novel systematic review will help identify the strengths and
124 weaknesses that exist and the gaps that must be addressed to inform future evidenced-based
125 policy at a national and global level. Therefore, the aims of this review are to:

126 a) Determine if attending nature-based ECE is associated with or has an effect on
127 children's physical health and development
128 b) Explore children's, parent's and/ or practitioner's perceptions of nature-based ECE on
129 children's physical health and development

130 The mixed-methods approach was chosen to better understand the phenomenon of nature-
131 based ECE (qualitative studies) and to measure its magnitude, trends, and effects on physical
132 development (quantitative studies). This approach combined the strengths of, and
133 compensated for the limitations of both research enquiries (29).

134 ## 2. Methods

135 This systematic review protocol was registered to the International Prospective Register of
136 Systematic Reviews (CRD42019152582) in October 2019 and published to BMC Systematic

Reviews in September 2020 (30) and is being reported in accordance with the reporting guidance provided in the Adapted PRISMA for reporting systematic reviews of qualitative and quantitative evidence (31). This systematic review is part of a research project synthesizing evidence on the relationship between nature-based ECE and children's overall health and development (30). Findings for other outcomes will be presented in a separate publication.

Eligibility criteria

The selection criteria followed the widely used PI(E)COS (**P**opulation, **I**ntervention or **E**xposure, **C**omparison, **O**utcomes and **S**tudy design) framework.

Population: Children aged 2-7 years attending ECE and who have not started primary or elementary school education were included. Children aged 2-7 years were chosen because this age group would typically attend ECE, accounting for global differences in ECE age range. Mean age, range or median reported in the study was used to assess eligibility. In instances where age was not reported, the study was included if it was conducted in an ECE setting. Studies that solely included a child population with disease conditions (autism, physical disability, attention deficit hyperactivity disorder, autism etc) were excluded.

Exposure/Intervention: Studies were included if they incorporated nature into the ECE environment; For example, this may have involved children spending most of the ECE day outdoors in nature; interventions aimed at enhancing the amount and diversity of nature in the ECE playgrounds; the introduction of a garden-based intervention within the ECE curriculum; or the exploration of the associations of specifical natural elements (e.g. hills, trees, grass, vegetation etc.) in the ECE setting on physical health outcomes. Studies that did not include nature in ECE settings were excluded; for example, traditional ECE where children would typically spend more time indoors and/or their environment was

predominately manmade structures such as slides, swings or climbing frames. The exposures were categorised once full text had been agreed and detail of these categories can be found in the methodology section.

Comparison: Comparison exposures where children attended traditional ECE that were typically indoors with provided less opportunities to spend time outdoors in an area that was not predominately nature-based. These outdoor areas tended to incorporate manmade structures.

Outcomes: Any child-level outcome related to physical health and development were included. For example, physical activity, motor competence, sleep, harms etc. Studies which included outcomes that were not child-level; for example, impact on practitioners were excluded, as were papers focused on changes (i.e. outcomes) to the ECE setting and studies using unvalidated questionnaires were (for both quantitative and qualitative designs).

Study designs: Both quantitative and qualitative primary research designs were included. Qualitative studies were included if they explored perceptions on children's physical health (from parent, practitioner or child) at a time when the child attended nature-based ECE. Qualitative studies were only included if they had a comparator (i.e., exposure, control group, pre/post) to understand whether there were improvements in child physical outcomes compared to baseline, the norm and/or other exposure. Quantitative study designs were included if outcomes were measured when children attended nature-based ECE, for example: cross-sectional and case-control studies measured when the child attended nature-based ECE; longitudinal, quasi-experimental and experimental studies with at least two time points; and retrospective studies if outcomes were assessed when the child attended nature-based ECE. Studies where the outcome could not be readily associated with the exposure (e.g. assessed

the impact of attending nature-based ECE after the child had left) or reviewed only one child (e.g. case studies) were excluded.

Information sources and search strategy

All searches were concluded in August 2020. In October 2019, nine relevant electronic databases were searched (from inception onwards):

1. Education Research Information Centre (ERIC) – (EBSCOhost)
2. Australian Education Index – (Proquest)
3. British Education Index – (EBSCOhost)
4. Child Development and Adolescent Studies – (EBSCOhost)
5. Applied Social Sciences Index and Abstracts – (Proquest)
6. PsycINFO – (EBSCOhost)
7. MEDLINE – (EBSCOhost)
8. SportDiscus – (EBSCOhost)
9. Scopus (Elsevier).

Grey literature was searched in Dissertation and Theses Database (ProQuest), Open Grey (www.opengrey.eu), and Directory of Open Access Journals (www.doaj.org) to capture dissertations and reports. The first 10 pages of Google Scholar were searched and checked, and websites of relevant organisations, professional bodies and other organisations involved in outdoor learning and play were searched for relevant publications. Finally, in August 2020, citation lists of eligible studies published from 2019 onwards were screened to identify recently published evidence that may have been missed in the initial searches.

Search strategies were constructed by three authors (AJ, AM and VW), two of which have topic expertise and one is an information scientist. To develop the comprehensive search

strategy, relevant systematic reviews and publications were reviewed for key words and related terms. Draft searches were reviewed and refined by the co-authors who have expertise in fields related to nature, child health and development, education, and systematic review methodology. The strategy was tested and refined until a finalised search strategy was developed. Search strategies were adapted for each database and other web searches. The literature search was not restricted by year of publication or language. A draft search strategy for MEDLINE can be found in Additional File 1 (30). References were imported to Endnote and duplicates removed by one reviewer (AJ).

Selection procedure

Titles and abstracts were screened once (AJ, PM, RC, IF, SI, FL, BJ, VW) with 10% screened in duplicate independently (AM). Using Covidence (www.covidence.org/) software, full-text articles were screened by two researchers independently in duplicate. In instances when reviewers disagreed, a third reviewer resolved any disagreement (AM). Where multiple publications were reported for the same study, they were combined and reported as a single study.

Data Extraction

Data from eligible studies was extracted by one reviewer (AJ) and cross-checked by another reviewer (AM, PM or HT).

For **quantitative studies**, the following information was extracted:

- Study ID (authors, year of publication)
- Country
- Study design (cross-sectional, controlled cross-sectional, controlled before and after etc.)

- Participants (age, gender, socioeconomic status, sample size etc.)
- Intervention/ exposure type and duration (nature-based ECE, ECE natural playgrounds etc.). Details on what any possible comparator groups received were also detailed (for example, characteristics of traditional preschool).
- Outcome measures (type, assessment tool, unit and time point of assessment etc.)
- Outcomes and results (effect estimates, standard deviation, confidence intervals etc.)

For **qualitative studies**, the following information was extracted:

- Study ID (authors, year of publication)
- Country
- Participants (i.e. age, gender, socioeconomic status, sample size etc.)
- Intervention/ exposure type and duration
- Research aims
- Outcome measures (interviews, focus groups etc.)
- Outcomes and results (summary of key themes derived from data extractor and author).

Primary study authors were not contacted to obtain missing information due to constraints on time and the large volume of studies.

Quality appraisal of included studies

The quality of all included studies was assessed at study level by two reviewers independently (AJ, AM, PM, HT) and disagreements resolved through discussion. The Effective Public Health Practice Project (EPHPP) Quality Assessment Tool (32) was used to assess the quality of **quantitative** studies. The EPHPP tool is a commonly used quality appraisal tool in public health that assesses quality across a variety of quantitative study designs (32). Minor modifications were made to the tool to ensure its relevancy for the

present review, for example, defining target population, specifying confounders of interest and enhancing the overall rating of the paper (see Additional File 2).

The Dixon-Woods (2004) checklist (33) was used to assess the trustworthiness of eligible **qualitative** studies which provides a set of prompts that were designed to appraise aspects qualitative methodology. Studies were excluded from the review if the research questions were not suited to qualitative inquiry (question 2) or if the paper did not make a useful contribution to the review question (question 7) (see Additional File 2).

Data synthesis

Data synthesis was done in three stages. Firstly, for quantitative studies we considered conducting meta-analyses, however, calculating an overall effect size estimate could not be performed because only a small number of studies could be pooled, studies were heterogenous (as interpreted by the I^2 statistic) and/or studies presented beta-coefficients only which introduce bias to the analyses when pooled. A sensitivity analysis, where studies with high risk of bias (i.e. poor study quality) are removed from the analysis, was also planned.

As a meta-analysis could not be performed, a Synthesis Without Meta-analysis (SWiM) based on effect direction was performed (34). In this study, the effect direction plot is used to summarise findings at **study level** in instances where an outcome is reported in two or more studies. Study level effect directions are then synthesised considering study quality, design and sample size to present a summary effect direction at an **outcome level**. The synthesis by effect direction addresses a question of whether there is evidence of a positive or negative association. In addition, a narrative synthesis summarising the effect direction was conducted in instances where outcomes could not be grouped in the effect direction plot. Outcomes were grouped into six sub-domains: physical activity, motor competence, weight status, sleep, UV exposure and harms were grouped by exposure which were determined after the screening

278 phase to aid interpretation of findings. The exposure categories were a) nature-based ECE, b)
279 ECE natural playgrounds and c) natural elements within ECE (see Table 1).

Table 1. Overview of the exposure categories

Nature-based ECE	This category represents studies with a higher exposure to nature. These ECE settings would integrate nature in their environment and children would spend most of their time outdoors in naturalised areas such as woods, forest and/ or naturalised playgrounds. Educators are usually present and may lead on structured educational activities.
ECE natural playgrounds	These studies tended to utilise interventions which have enhanced the nature in the ECE playground or studies which compare natural ECE playgrounds to ECE traditional playgrounds. Children would not typically spend as much time outdoors in these studies.
Natural elements within ECE	This category represents a lower exposure to nature and include studies (mostly cross-sectional in design) which looked at the association of specific natural elements within the ECE setting, such as trees, vegetation, hills, grass etc., or specific features or quality of the ECE playground on specific outcomes.

280

281 Sub-group analyses were initially planned to investigate differential associations, however,
282 the eligible studies limited our ability to conduct sub-group analyses (age, gender, duration
283 spent in ECE etc.).

284 Secondly, for qualitative studies, a thematic analysis of author reported conclusions and
285 participant quotes was conducted, grouping data into higher and lower order themes. One
286 reviewer (AJ) analysed the data inductively, generating themes which were discussed with
287 another two reviewers (AM, PM) who checked themes and clustering against quotes (both
288 authors' conclusion and participant quotes, were reported).

289 Finally, we integrated the syntheses of both qualitative and quantitative studies using a
290 conceptual matrix. Findings from the synthesis of quantitative studies were mapped against

the themes from qualitative studies identifying confirmative and contradicting findings. Findings from the qualitative synthesis were also used to hypothesise mechanisms of why or how quantitative results might have occurred.

Certainty of quantitative evidence

A Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework was used to assess the certainty of the evidence across studies at an outcome level (35). Where two or more studies reporting on the same outcome were grouped, the risk of bias, precision, consistency, and directness was assessed. Based on these assessments, the certainty of evidence was upgraded or downgraded to provide an overall rating for the certainty of the evidence: very low, low, moderate and high (35). Given the absence of randomised controlled trials (RCTs), the start rating was always low, however, as per GRADE guidance could be upgraded. Publication bias could not be assessed there was not enough studies grouped per outcome.

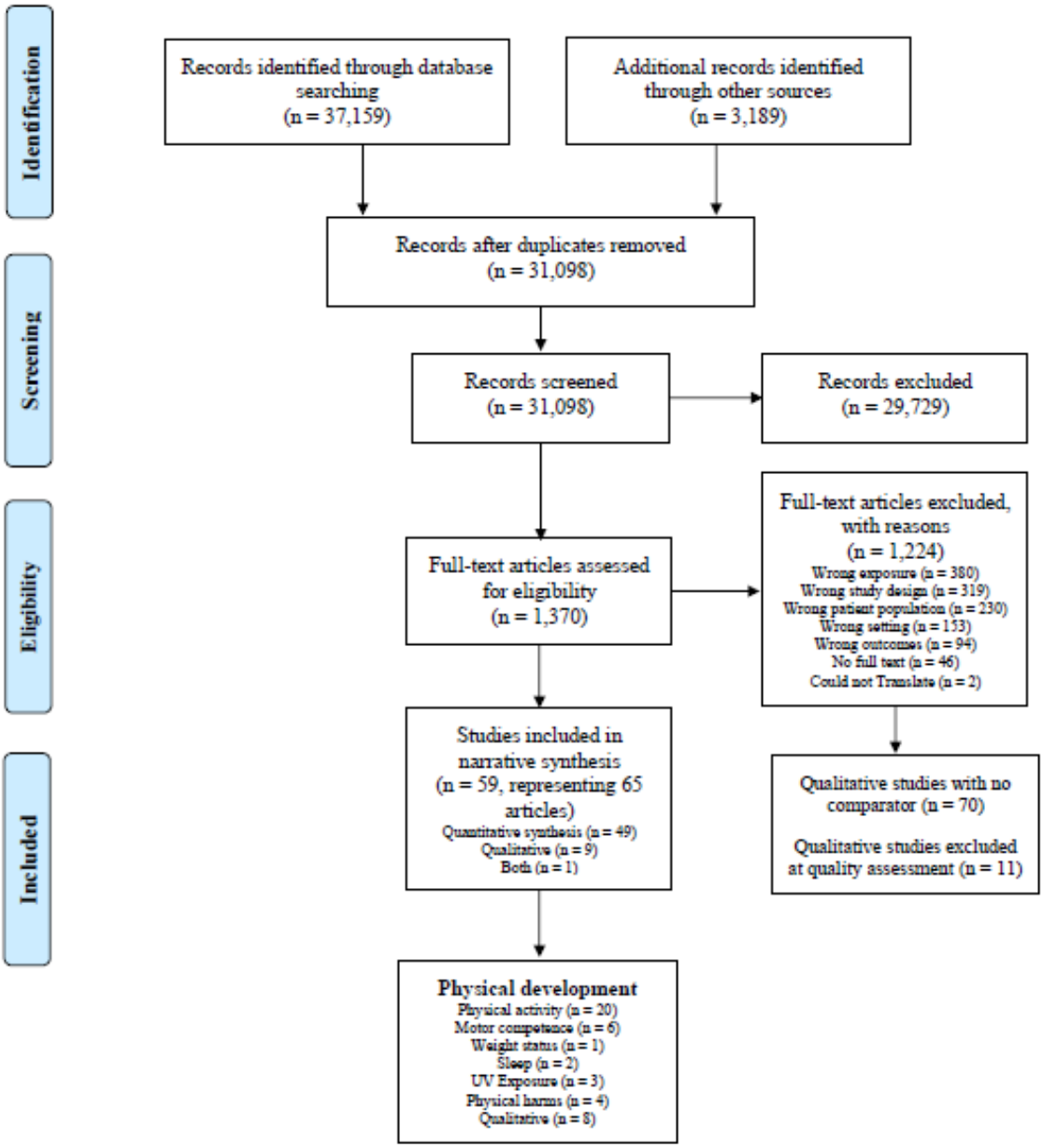
3. Results

Results of the literature search

Figure 1 presents the summary of results from the systematic literature search. The headline figures (i.e. total number of 'hits') relate to the broader systematic review which encompasses cognitive, social, emotional and environmental outcomes in addition to physical outcomes (reported in this paper) (30). After duplicates were removed, 31,098 articles remained, of which 29,729 irrelevant titles and abstracts were excluded leaving 1,370 full text articles to be screened. 1,224 full-text articles were excluded with reasons detailed in Figure 1. Seventy qualitative studies were removed because they did not have a comparator (i.e. exposure, control group, pre/post) as did a further 11 studies after having their trustworthiness assessed.

A total of 59 unique studies (representing 65 individual papers) met the inclusion criteria for this paper, of which, 39 included a physical outcome (31 quantitative and 8 qualitative).

Figure 1. Results from the literature search



Characteristics of the eligible studies

Geographical location

The majority of the studies were conducted in Norway (n=8) (23, 36-44), USA (n= 7) (45-51), Australia (n= 6) (52-57) and Canada (n=4) (58-61). Three studies each were conducted

in Finland (62-64), Germany (65-67) and Sweden (68-70). The remaining studies were conducted in Denmark (71), Italy (72), Netherlands (73), Slovenia (74) and South Korea (75) (n= 1 study per county).

Study designs

Most study designs were cross-sectional (n= 16). Fewer were controlled cross-sectional (n= 7), uncontrolled before and after (n= 2) and controlled before and after (n= 6). The remaining 8 studies were qualitative.

Exposures

Studies were separated into three exposures (described in the methods section): nature-based ECE (n=18), ECE natural playgrounds (n=8) and natural elements within ECE (n=13).

When studies included a control group, the control tended to be either a traditional ECE setting or traditional playground. In these conditions, children would spend more time indoors and their outdoor playground would predominately comprise of manmade structures such as swings and slides. There were instances where the control group also received some nature-based exposure, but this exposure was still less than in the experimental group.

Sample size and participant characteristics

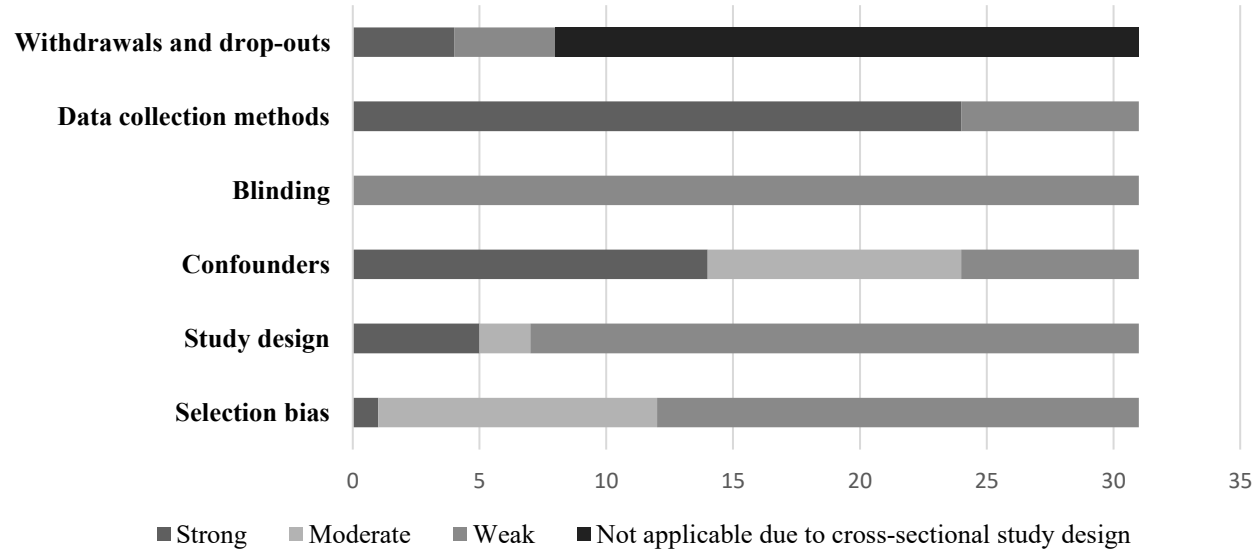
The total sample size of the combined eligible quantitative and qualitative studies was 8,306 (n= 6,275 experimental/exposure group; n= 2,031 control). Sample sizes were small across the 39 eligible studies; only nine studies had a sample size greater than 200 (39, 51-53, 55, 62, 63, 65, 71), of which seven were cross-sectional or controlled cross-sectional (39, 53, 55, 62, 63, 65, 71) and two were controlled (52) or uncontrolled before and after (51). Sample size in the qualitative studies ranged from 12 (56, 64) to 75 participants (57).

Socioeconomic status (SES) was infrequently reported, but when it was reported it was generally moderate to high SES.

Quality of included quantitative studies

The quality of each study as assessed by the EPHPP tool can be found in Additional File 4. Of the eligible studies, only three studies were of moderate quality (52, 61, 75) with the remaining rated as weak. Of the three studies rated moderate quality, they represented each exposure (n=1 nature-based ECEs, n= 1 ECE natural playgrounds, n=1 natural elements within ECE). Figure 2 presents the quality rating across the 31 eligible quantitative studies by assessment item. Typically, items were rated weak because of selection bias, study design and it was unclear whether the outcome assessors and/ or participants were aware of the research questions (blinding). A weak rating for study attrition (withdrawals and dropouts) was provided in 50% of controlled before and after studies. Data collection methods tended to be valid and reliable, and confounders were rated strong or moderate in 24/31 studies.

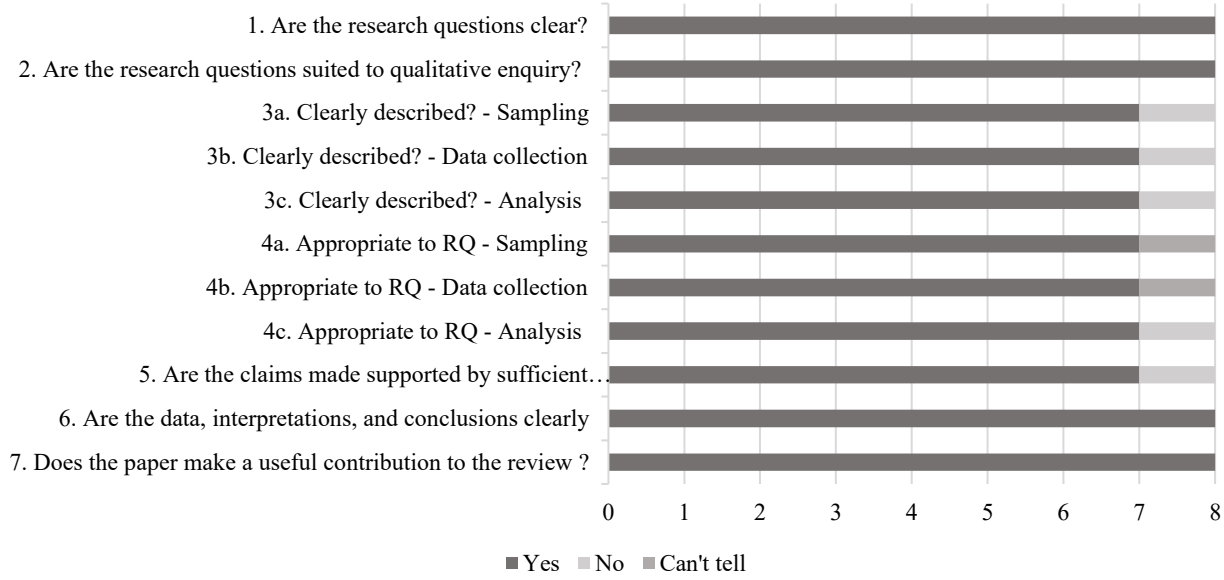
Figure 2. Quality of quantitative studies by assessment item.



Trustworthiness of included qualitative studies

Figure three presents the findings of the trustworthiness of the included qualitative studies. Sampling (3a), data collection (3b) and analysis (3c) were **not** clearly described, analysis (4c) was **not** appropriate to the research question, and claims were **not** supported by sufficient evidence on one occasion. Finally, we couldn't tell if sampling (4a) and data collection (4b) was appropriate to the research question on one occasion.

Figure 3. Trustworthiness of qualitative studies by assessment item.



Main findings - Quantitative studies

1. Physical activity (n=20 studies)

Of the eligible studies, 15 studies measured physical activity levels and sedentary time using devices; of which, 12 studies used the ActiGraph accelerometer (42, 47, 52-55, 58, 61-63, 71, 73), two studies used pedometers (67, 69) and one study used Global Positioning System (GPS) devices (74). The remining five studies used observational methods such as the Observational System for Recording Physical Activity in Children-Preschool (OSRAC-P) or Children's Activity Rating Scale (CARS) (40, 41, 48, 51, 59).

1.1. *Nature-based ECE (n= 4 studies, n= 250 children)*

Table 2 presents the effect direction plot for device-measured sedentary time (mins/ ECE day) and MVPA (mins/ ECE day) in eligible studies where these outcomes were reported in more than one study (47, 58). One study showed a non-significant, but positive association on sedentary time (i.e. lower sedentary mins/ ECE day) favouring children attending nature-based ECE compared to traditional ECE (58). The other study demonstrated a negative association (non-significant, mean difference= - 13.5 mins-ECE day; 95% CI: 63.3, 54.2) where sedentary time was higher in children who attended nature-based ECE compared to traditional ECE (47). For MVPA (mins/ ECE day), one study demonstrated a positive, but non-significant association where children attending nature-based ECE engaged in 6 minutes more MVPA compared to children attending traditional ECE (58). The other study showed a negative association where children who attended nature-based ECE engaged in 1.5 mins/ ECE day (95% CI: -2.8, 1.2) less MVPA compared to children attending traditional ECE (47).

Additionally (not presented in Table 2), one study reported that children who attended nature-based ECE engaged in higher levels of habitual (mins/day) sedentary time and less light physical activity and MVPA across the full week, weekday and weekend compared to children who attended traditional ECE (47). The two studies that assessed physical activity using observational methods reported, i) that children who attended nature-based ECE were less stationary and engaged in more slow-easy and moderate physical activity compared to traditional ECE (59), and ii) children who attended nature-based ECE engaged in a range of physical activity types (48).

1.2. ECE natural playgrounds (n= 5 studies, n= 910 children)

Following one intervention study where playgrounds were enhanced to incorporate more nature, device measured MVPA significantly decreased from baseline to follow-up by 1.32 mins/outdoor time (0.37 SE, $p< 0.001$) (61). However, a second intervention study indicated non-significant improvements from baseline to follow-up on MVPA (moderate to fast physical activity) and statistically significant improvements on physical activity ($p= 0.001$) and non-sedentary physical activity (slow to fast physical activity) ($p= 0.001$) as measured by Children's Activity Rating Scale (CARS – observational assessment) (51). In this study, physical activity was a continuous variable including all five categories of the CARS assessment (1= stationary or motionless, 2= stationary with limb or trunk movements, 3= slow-easy, 4= moderate, and 5= fast), whereas MVPA (scored 4 or 5) and non-sedentary physical activity (scored 3, 4 or 5) were dichotomised (51). The other three cross-sectional studies found there was an association (p= 0.01) between CPM (raw total physical activity data collected by an accelerometer) in the natural and traditional (measured in spring and winter) playgrounds meaning CPM was similar across the environments (42); pedometer measured gait cycles/ min were lower in a nature playground ($p= 0.109$) compared to a traditional playground (67); and children covered a greater distance (km) ($p= 0.132$) when in a natural playground versus a traditional playground (74).

1.3. Natural elements within ECE (n= 11 studies, n= 3,663 children)

For the effect direction plot (see Table 3), six studies were grouped together for device measured MVPA. One study demonstrated a significant ($\beta= 0.27$, $p< 0.01$) association between natural elements (includes trees, shrubs, plants, hills, grass, rocks etc.) and increased MVPA (73). The other two studies suggested that higher vegetation (height in metres) (53) and natural elements (includes trees, shrubs, plants, logs, hills, grass, rocks etc.) (55) had a

positive, but non-significant, association with MVPA. One study reported a non-significant difference between the experimental and control group (52) and two studies demonstrated a negative association (one significant, one non-significant) (54, 71). These studies demonstrated that MVPA decreased as number of hilly landscapes (71), natural surfaces (54) and vegetation (54, 71) increased.

Four studies were grouped together for device measured total physical activity. Vegetation, natural elements, grass, and rocks had a positive association with total PA (min/ECE day) in three studies, but these were non-significant (53, 55, 62). One study reported non-significant difference for natural elements between the experimental and control groups (52). Although Määttä et al (2019) reported a non-significant positive association for some natural elements (grass, rocks), they also reported that forest and trees were negatively associated (non-significant) with total physical activity (mins/ ECE day) (62). Additionally, two studies that assessed total physical activity using observational methods reported that nature was not a predictor of physical activity (40) and not associated with observations with high wellbeing and physical activity (41). These studies could not be grouped together in the effect direction plot because one study measured physical activity only (40) and the other combined physical activity and wellbeing (41).

Three studies were grouped together for device measured sedentary time (54, 63, 73), of which two demonstrated a significant positive association (in the case of sedentary time this is reflected by a negative statistical association, i.e. higher natural elements/lower sedentary time) (63, 73) and one demonstrated a non-significant negative association (54). For example, higher frequency of nature trips ($\beta = -1.026$, 95% CI: −1.804, −0.248), $p = 0.010$) (63) and natural elements ($\beta = -0.31$, $p < 0.001$) (73) were significantly associated with lower levels of sedentary time (63). Natural surfaces (used in effect direct plot as this variable is comparable

449 to other studies that assessed sedentary time) and vegetation were associated with increased
450 sedentary time (all non-significant)) (54). However, this study also reported hills and shade
451 were associated with lower levels of sedentary time (mins/ outdoor time) (54).

452 For step counts, one study reported a significant association (p<0.001) with high
453 environment score (playgrounds which had a large outdoor area and integrated play areas
454 with natural elements) (69). Similarly another study reported a significant positive
455 association between natural elements and step counts (55).

456 Two studies demonstrated a positive association between natural elements and CPM (55,
457 73), of which one reported a significant association on habitual CPM (β= 0.21, p< 0.01) (73).

Table 3. **Natural elements within ECE** on physical activity

Study ID	Study Design	Sample size (E/C)	Study quality	Sedentary time ⊕	MVPA ⊕	Total PA ⊕	Step counts ⊕	CPM ⊕
Ng et al (2020)[52]	Controlled before & after	159 / 138	Moderate	-	■	■	-	-
Boldemann et al (2006)[69]	Cross-sectional	199	Weak	-	-	-	▲	-
Christian et al (2019)[53]	Cross-sectional	678	Weak	-	▲	▲	-	-
deWeger (2017)[55]	Cross-sectional	274	Weak	-	▲	▲	▲	▲
Gubbels et al (2018)[73]	Cross-sectional	151	Weak	▲	▲	-	-	▲
Määttä et al (2019b)[63]	Cross-sectional	655	Weak	▲	-	▲	-	-
Olesen et al (2013)[71]	Cross-sectional	441	Weak	-	▼	-	-	-
Sugiyama et al (2012)[54]	Cross-sectional	89	Weak	▼	▼	-	-	-
Summary effect direction				▲	►	▲	▲	▲

Abbreviations: E= experimental; C= comparison; MVPA= moderate-to-vigorous physical activity; PA= physical activity; ECE= Early childhood education.

GRADE – (assesses the certainty of evidence at an outcome level):
⊕ = Very low

Effect direction:

Study level: ▲= positive association with nature-based ECE; ▼= negative association with nature-based ECE; ■ = statistics not presented.

Controlled before & after studies – difference between experimental and control group at follow-up (unless stated). Uncontrolled before & after studies – change since baseline (unless stated). Controlled cross sectional – difference between experimental and control (unless stated). Cross-sectional – positive, negative or no association.

Summary: ▲= studies show a positive association with nature-based ECE; ▼= studies show a negative association with nature-based ECE; ► = conflicting findings

Summary effect direction considers study quality, design (i.e. controlled before and after weighted more than cross-sectional) and sample size.

458

2. Motor competence (n= 6 studies, n= 430 children)

2.1. *Nature-based ECE*

Within the effect direction plot (presented in Table 4), three studies were grouped together for balance and speed and agility (23, 36-38, 66), and two for object control skills (38, 58). For balance, a significant positive relationship was found in two studies in children who attended nature-based ECE compared to traditional ECE (23, 36, 37, 66), with one other study suggesting better balance in traditional settings (38). For object control skills, one study reported a non-significant positive association in children who attended nature-based ECE compared to traditional ECE (58), the other suggested that there was a non-significant association between object control skills and nature-based ECE (38). For studies assessing speed and agility, one study highlighted a non-significant positive association with nature-based ECE compared to traditional ECE (23, 36, 37). The other two studies were suggestive that children's speed and agility was better in the traditional ECE compared to the nature-based ECE (23, 36-38, 66).

For outcomes that could not be grouped and presented in an effect direction plot, one study reported higher scores in body awareness, gross motor skills and fine motor skills in children who attended nature-based ECE compared to traditional ECE (all non-significant) (72). Locomotor skills (running, skipping, hopping) were significantly (p= 0.03, η2= 0.06) better in children who attended nature based ECE compared to traditional ECE; however, perceived motor competence was marginally lower in children who attended ECE (non-significant) (58). Total motor competence (including manual dexterity, ball skills and balance) and total fitness scores were lower in children who attended nature-based ECE compared to traditional ECE (non-significant) (38). Scores for skipping were also significantly better in children who attended nature-based ECE compared to traditional ECE at follow-up (23, 36, 37). Finally, children who attended nature-based ECE performed significantly better in a measure of

484 strength (hanging on pull up bar) and jumping compared to children who attended traditional
485 ECE (66).

486 **3. Weight Status (n= 1 study, n= 172 children)**

487 ***3.1. Natural elements within ECE***

488 Findings from one study reported a non-significant association between children who
489 attended ECE settings with high environment quality (i.e. large space, vegetation, tress etc.)
490 and BMI (p= - 0.07) and waist circumference (p= 0.25) compared to low environmental
491 quality (70).

Table 4. **Nature-based ECE** vs traditional ECE on motor competence and physical harms

Study ID	**Study Design**	**Sample size (E/C)**	**Study quality**	**Balance** ⨁	**Object Control** ⨁	**Speed & agility** ⨁	**Illness** ⨁
Ene-Voiculescu & Ene-Voiculescu (2015)[23, 36, 37]	Controlled before & after	46 / 29	Weak	▲		▲	-
Müller et al (2017)[58]	Controlled before & after	43 / 45	Weak	-	▲	-	-
Lysklett et al (2019)[38]	Controlled cross sectional	43 / 49	Weak	▼	▼	▼	-
Scholz & Krombholz (2007)[66]	Controlled cross-sectional	45 / 84	Weak	▲		▼	-
Frenkel et al (2019)[46]	Controlled cross-sectional	71 / 70	Weak	-	-	-	▲
Moen et al (2007)[39]	Controlled cross-sectional	267 / 264	Weak	-	-	-	▼
Summary effect direction				▲	►	►	►

Abbreviations: E= experimental; C= comparison; ECE= Early childhood education.

GRADE – (assesses the certainty of evidence at an outcome level):
⨁ = Very low

Effect direction:

Study level: ▲= positive association with nature-based ECE; ▼= negative association with nature-based ECE.

Controlled before & after studies – difference between experimental and control group at follow-up (unless stated). Uncontrolled before & after studies – change since baseline (unless stated). Controlled cross sectional – difference between experimental and control (unless stated). Cross-sectional – positive, negative or no association.

Summary: ▲= studies show a positive association with nature-based ECE; ▼= studies show a negative association with nature-based ECE; ► = conflicting findings

Summary effect direction considers study quality, design (i.e. controlled before and after weighted more than cross-sectional) and sample size

492

4. Sleep (n= 2)

4.1. *Nature-based ECE (n= 1 study; n= 37 children)*

Sleep was assessed using the Children's Sleep Habits Questionnaire (CSHQ) which consists of eight sleep domains: bedtime resistance, sleep onset delay, sleep duration, sleep anxiety, night wakings, parasomnia, sleep-disordered breathing, and daytime sleepiness (75). Total sleep time was also assessed. All sleep domain scores were better in children who attended nature-based ECE compared to children who attended traditional ECE; total CSHQ score ($p<$ 0.01), sleep disordered breathing ($p=$ 0.04) and daytime sleepiness ($p<$ 0.01) were significantly different (75). Total sleep time was marginally higher in children who attended nature-based ECE (10.5 hours ± 1.0 vs 10.4 hours ± 0.9) compared to children who attended traditional ECE, but this was non-significant (75).

4.2. *Natural elements within ECE (n= 1 study; n= 172 children)*

There was a significant association ($p=$ 0.03) between environment quality and mean sleep time (minutes) (70). Children who attended ECEs with high environment quality had a mean sleep time of 658 minutes ± 44 compared to lower environment score 642 minutes ± 32 (70). ECE playgrounds with a high environment quality are ones which have a large space, trees, vegetation, hilly terrain and integrated with play structures.

5. UV Exposure (n= 3 studies, n= 941 children)

5.1. *Natural elements within ECE*

UV exposure was lower and significantly associated with ECE playgrounds with a higher environmental quality in three studies (53, 68, 69). ECE playgrounds with a higher environmental quality are those that have vegetation and trees integrated into the playgrounds to provide sufficient shade for children (53, 68, 69).

6. Harms (n= 4)

6.1. *Nature-based ECE (n= 3 studies, n= 2,379 children)*

Two studies assessed illnesses and sickness absenteeism using parent or teacher reported days absent from school (39, 46). Based on the effect direction plot (Table 4), one study found a non-significant positive association between nature-based ECE and illnesses (i.e. illnesses were lower in children who attended nature-based ECE) (46). The other study reported a non-significant ($p > 0.05$) negative association between nature-based ECE and sickness absenteeism (i.e. sickness absenteeism was lower in children who attended nature-based ECE) (39).

Other harms reported related to minor injuries (e.g., wounds, cuts and sprains) and tick bites and borreliosis (or Lyme's Disease). For minor injuries, one study reported non-significantly less minor injuries for boys who attended nature-based ECE compared to traditional ECE (46). However, minor injuries were significantly higher for girls who attended nature-based ECE compared to traditional ECE (46). Tick bites and borreliosis were significantly more prevalent in nature-based ECE compared to traditional ECE (73% vs 27% and 2% and 0.4% respectively) (65).

6.2. *Natural elements within ECE (n= 1 study, n= 172 children)*

One study reported no association ($p = 0.12$) between environment quality (high and low) and symptoms of illness (runny nose, cough fever, respiratory problems etc.) (70).

Main findings- Qualitative studies

Eight studies were included in the thematic analysis, of which, five studies involved nature-based ECE and three studies were ECE natural playgrounds (study characteristics of qualitative studies can be found in Additional File 3). Studies tended to use direct observation

539 and interviews (predominately with educators) to collect qualitative data. Findings from the
540 thematic analysis are presented in Figure 4 and show four higher order themes.

541 ***Theme 1. Natural settings provide more affordances compared to traditional***
542 ***settings***

543 Theme 1 indicated the importance of the natural environment for affording opportunities to
544 enhance a range of physical outcomes. For example, six of the included studies noted that the
545 natural environment enabled children to engage in more physical types of play, such as risky,
546 active and free play (43, 49, 50, 56, 57, 64). The importance of the natural environment for
547 engaging in MVPA was noted in two studies (44, 64). This connection between play, motor
548 competence and physical activity afforded by the natural environment can be summarised in
549 the following quote:

550 *"High physical-motor levels are created, the children jump down and run back up.*
551 *They talk, shout and laugh. Three of the girls jump together and try to land in*
552 *differing ways. They hold hands and try to jump together from the small knoll. There*
553 *is laughter. They are eager and enduring. The small knoll has many opportunities for*
554 *variation, in height and width, which invite challenges suitable for each child's*
555 *resources. The children have visual, verbal and physical contact with each other. The*
556 *top of the knoll provides an overview. Some find it scary the first time they try, but*
557 *together they challenge each other, supporting and encouraging each other. The*
558 *children decide how much they will participate and how they jump, and how they wish*
559 *to solve the challenges offered by the knoll"* (44).

560 This quote also highlights "risk" in children's play. Risky play is characterised by play that is
561 "thrilling and exciting and where there is a risk of physical injury" (76). Although, this may
562 seem potentially harmful to children, this type of play is important for children's

development as children actively engage in risk assessment, in which they must judge the benefit and consequences of dealing with such unpredictability (77). It was reported that the natural environment afforded higher levels of risk in two studies (43, 60).

> *I like playing in the fallen logs and trees on the playground; it is so much fun, but a bit scary too! I like the big pile of sticks and logs that we made – it is for another fort that is going to be really high off the ground"* (60).

The final aspect of this theme relates to the importance of social interactions in relation to encouraging play and physical activity. Four studies also noted the importance of teachers and educators' interactions with children in relation to encouraging play and physical activity (44, 49, 56, 60).

> *"I try to do different things with them every day. Like I said, we play with them at least ten minutes. So, I try to run, parachute, the blocks, climbing, sliding down the slides"* (49).

Theme 2. Natural and traditional settings provide similar affordances

Despite Theme 1 indicating the importance of affordances for a range of physical outcomes, some studies also reported that setting type provided similar affordances. Two sub themes were reported: a) movement types and intensity were similar across natural and traditional playgrounds (57) and b) frequency of risky play is similar in both nature-based and traditional ECE settings (43). The latter sub-theme relates the findings reported on risky play in Theme 1. Taken together, children will seek risk irrespective of playground type, however, the nature-based ECE affords greater risk (Theme 1) (43).

> *"Comparing the two play environments, they both seem to include an extensive amount of affordances for risky play. At both preschool playgrounds, there are*

opportunities for play in great heights such as climbing, jumping down, and balancing and as well as opportunities for play with high speed such as swinging, sliding/sledding, running, and bicycling." Taken from authors conclusions (43).

Theme 3. Natural environment is more diverse and engaging, and preferred by children for play compared to traditional settings

Two studies reported children's preference for the natural environment (44, 60). It appears when children are outdoors in nature it affords them the opportunity to play in a diverse environment with their friends and this combination provides enjoyment.

"I like going outside and playing! I like playing with my friends, Sydney and Megan. We play hide and seek on the playground and hide in the forest in the logs and trees. I like outside because it's so fun and I really like to play. Sometimes I play with my sister too; I like all the colours outside and all the space" (60).

Theme 4. Restorative and invigorating effect of nature

One study indicated the importance of the natural playground in helping children invigorate and/or restore their energy for play and physical activity (64). For example, the natural environment for some children provides them with more energy to continue playing, however, other children may feel the requirement to nap thus restoring their energy to engage in more play.

"Now it's become very difficult to finish playing. They would rather continue, and those who need to take a nap, they've had a nice, long time outdoors and nice games so they fall asleep more easily, and it affects their energy in the afternoon. Some children have very long days here. They come in the morning and stay until five o'clock; they seem to be somehow energetic and lively in the yard. This is new for us.

The contrast to the previous yard is so great that the effects can be seen here very quickly" (64).

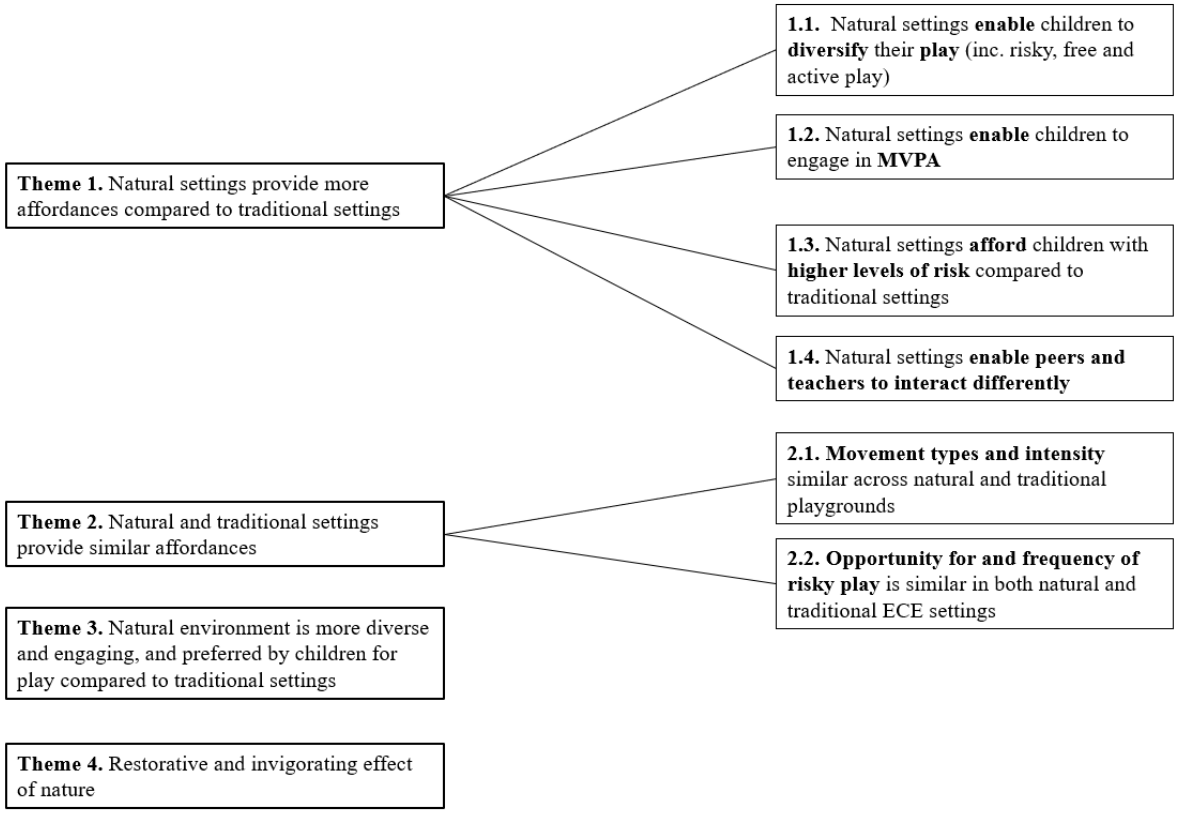


Figure 4. Findings from the thematic analysis

Synthesis of quantitative and qualitative findings

Of the outcomes assessed in quantitative studies, sedentary time, weight status and UV exposure did not appear as a theme from the qualitative studies. Additional File 6 shows the matrix relating themes from the qualitative evidence synthesis with the findings from the quantitative evidence synthesis. The matrix indicates where findings from the two data sources were confirmatory or conflicting. Themes not present in the matrix reflects where data could not be directly linked to the results of the quantitative synthesis. However, these themes were considered for generating a hypothesis on how or why observed quantitative results occurred.

Findings from the quantitative synthesis suggested that some aspects of motor competence, such as balance, are better in children attending nature-based ECE compared to traditional settings. This might be achieved because natural settings enable children to diversify their play, engage in a range of physical activity types and allow a different child-child and child-educator interaction (i.e. encourage more play interactions). Nature-based ECE might also afford children with higher levels of risk compared to traditional ECE which foster development of motor competence to a greater degree (see Figure 5 for visual representation). Limited evidence from quantitative studies did not support the theme that *any* of the natural spaces (nature-based ECE, ECE natural playgrounds and natural elements within ECE) enable children to engage in MVPA (device measured). The educator observed benefit of natural settings for higher intensity physical activity (Figure 4) might be achieved through the perception that the natural environment is more engaging and preferred by children compared to traditional settings. The restorative and invigorating effects of nature - manifested in higher energy levels for play and/or the requirement to nap to restore energy levels - could benefit the duration in which children engage in higher intensity physical activity. While the perceived higher level of risk in nature-based ECE compared to traditional ECE might benefit the development of motor competence, time spent in MVPA might be reduced to manage (i.e. more deliberate and slowed movement) the riskier situations (see Figure 6). Equally, a similar opportunity and frequency of risky play in both natural and traditional spaces (ECE setting and playground) might explain why the theme 'Movement intensity is similar across natural and traditional spaces' is not supported by findings from the quantitative synthesis.

Figure 5. Hypothesized pathway on how Nature-based ECE can benefit motor competence.

An arrow denotes where factors are hypothesised to lead to better motor competence

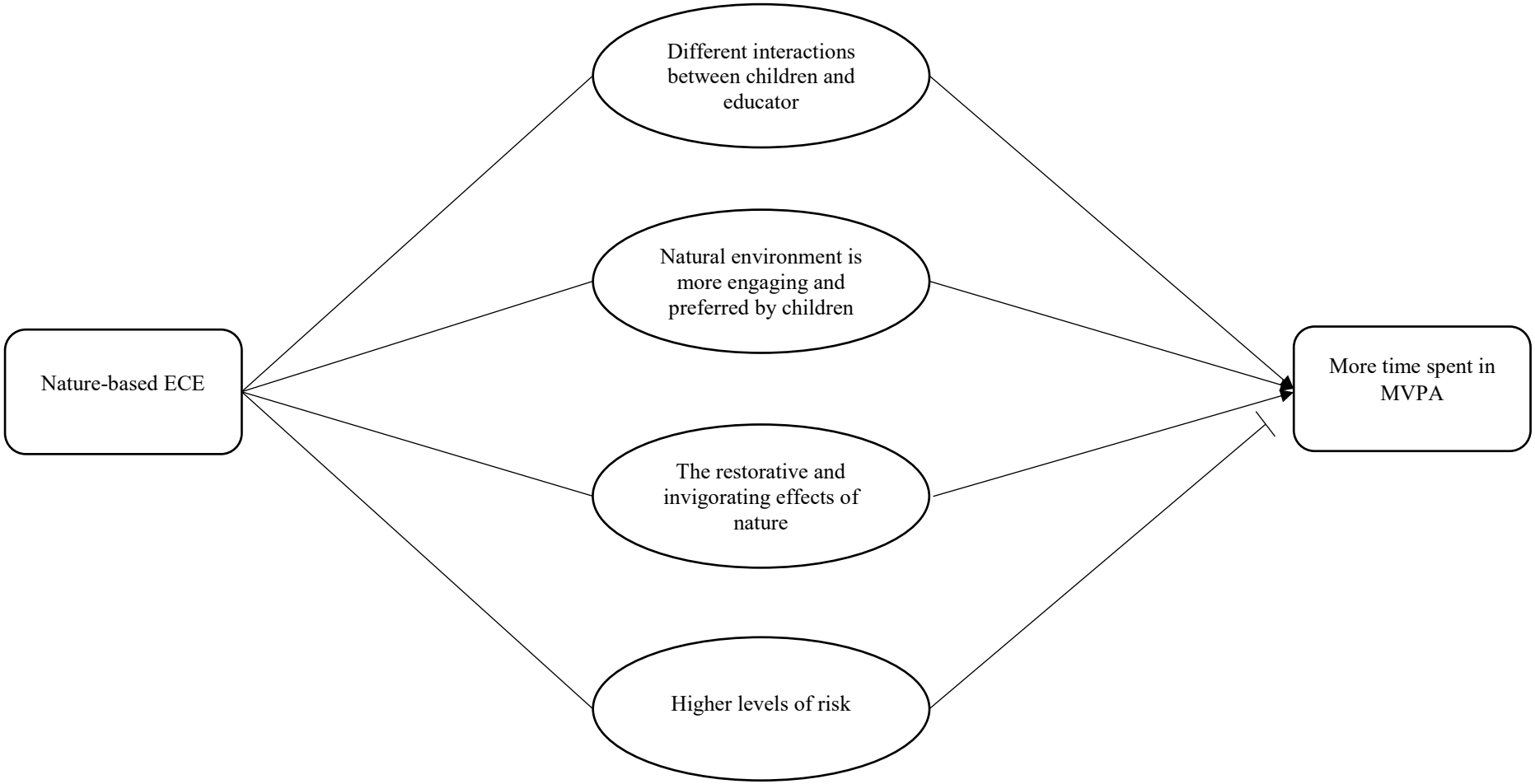


Figure 6. Hypothesized pathway on how Nature-based ECE might influence MVPA levels.

An arrow denotes where factors are hypothesised to lead to more time spent in MVPA. A blocked end highlights high levels of risk does not lead to more time spent in MVPA.

4. Discussion

This systematic review aimed to understand whether nature-based ECE is associated with children's physical activity, sedentary behaviour, motor competence and other physical health outcomes. Based on the effect direction plot, findings indicated inconsistent associations between nature-based ECE and children's sedentary time, MVPA, speed and agility, object control skills and illnesses. However, positive and consistent associations were found for balance. Consistent positive associations were also found between specific natural elements (e.g. vegetation) and different physical activity types (sedentary time, total physical activity, step counts and CPM).

Physical activity was the most assessed outcome across the three exposure categories. Findings were inconsistent for the association of attending nature-based ECE on children's sedentary time and MVPA during the ECE day. These inconsistent findings have been found in other conceptually similar systematic reviews. For example, a systematic review that aimed to understand the impact of participating in nature play on children's (2–12 years) on physical activity levels found that, of the five studies that used device measured physical activity, only one study reported a significant difference and three studies reported no change (28). One reason for this finding might be that studies were underpowered to detect differences between exposures. In the present review, the two studies that assessed the association between nature-based ECE on children's physical activity had small sample sizes (<50 in experimental group) and, therefore, are unlikely to be adequately powered to detect changes in physical activity. Another reason might be that level of risks afforded in the nature-based ECE was too high to allow an increase in time spent in higher physical activity levels. Similarly, other factors such as interactions between children and educators could influence physical activity levels. Lack of assessing factors that might mediate or moderate the associations between nature-based ECE on children's physical activity make it difficult to interpret the observed result. Despite not being able to draw conclusions on the effect of **nature-based ECE** on children's

physical activity levels, evidence from cross-sectional studies indicated certain **natural elements** (e.g. vegetation, grass etc.) were positively associated with different physical activity intensities. However, these studies are limited in that they cannot determine casual inference.

However, a further important consideration regarding MVPA and other physical activity outcomes is that the inconsistent findings across reviews including the current study is perhaps indicative of it being poorly matched, theoretically, as an important outcome. Mechanistically, MVPA may not be the most appropriate outcome resultant from engaging in nature-based ECE, where the affordances created by the diverse natural environment provide opportunities for children to engage in diverse types of play (sociodramatic, symbolic, narrative etc.) on their own terms, but this may not manifest in high intensity physical activity as such. However, the benefits of engaging in diverse play types, despite potentially not being high intensity, may impact other important outcomes such as motor competence and other outcomes not presented in this paper, such as general wellbeing, cognitive, and social and emotional outcomes. This speaks to a related issue in this field, on how to best capture the range of movement behaviours that children are likely to participate in. In eligible studies that used device-measured physical activity, the ActiGraph accelerometer was the most commonly used method. The ActiGraph accelerometer is useful for physical activity *intensity*, such as measuring time spent in MVPA, however, it has important limitations in that it cannot accurately detect changes in posture (78) or upper body movement (if the monitor is placed at the hip). In nature-based ECE, children will engage in a range of full-body movement *behaviours* through play that the ActiGraph may be unable to detect, such as climbing, balancing, or lifting objects. Device measured engagement in physical activity is a step forward in our understanding of nature-based ECE programme effects. However, it is important that consideration is given, in pre-evaluation stages of development, to the appropriate measurement tools to capture the desired physical manifestation of the outcomes deemed to be a consequence of engaging in nature-based ECE. For instance, where postural classification (e.g. sit, stand, step) or postural change is deemed to be an important outcome of interest, the activPAL (79); or an alternative method, such as direct

observation might be more suitable for measuring children's range of movement in nature-based ECE, such as climbing, jumping, balancing etc. Where possible, measurement of movement (e.g. physical activity, play, motor competence) should be well thought out as part of the evaluation design, where strengths and limitations are discussed and ideally using participatory approaches with a variety of informed stakeholders.

Given the lack of supportive evidence for MVPA in this review, motor competence, likely developed through engaging in a range of play types in nature-based ECE, may be a more appropriate outcome which would manifest in higher levels of MVPA as children mature into adolescence. For motor competence outcomes, findings indicated a positive association between nature-based ECE and children's balance, and inconsistent findings on speed and agility, and object control skills. Speed and agility used a standard shuttle run, and although there were inconsistent associations, these differences between nature-based ECE and traditional ECE were marginal. When examining similar systematic reviews in this area, positive associations between exposure to nature on children and adolescents (0-12 years) fine and gross motor skills have been reported (27). Of the observational studies, 66.6% indicated association between nature and fine and gross motor skills; in the experimental studies, 60% reported improvements in gross motor skills (27). Existing literature has indicated that motor competence in preschool children tends to be low (15) and more robust studies with larger samples are required to understand whether nature-based ECE improves motor competence more than the developmental norm. Improvement in motor competence is particularly important as the early years (2-7 years) is the period when motor competence development occurs (80), and it underpins physical activity (13, 14). Future work may also consider exploring different motor competence *categories*, stratified by gender, as previous research has suggested that object control skills are associated with increased physical activity for boys and locomotor skills are associated with increased physical activity for girls (15, 81). In addition, as our integrated analysis of quantitative and qualitive data revealed, assessment of play, risk, physical

764 activity type, and child-educator interaction might provide further insights into how nature-based
765 ECE can achieve improvements in children's motor competence.

766 The remaining outcomes, weight status (n= 1)**,** sleep (n= 2)**,** UV exposure (n= 3) and physical
767 harms (n= 4) were only assessed in a small number of eligible studies. Limited measurement of
768 other physical outcomes seems common among conceptually similar systematic reviews (27, 82).
769 One systematic review exploring the influence of nature experiences on children and adolescent's
770 BMI found improvements (non-significant) in weight status across four eligible studies (82);
771 however, the quality of evidence was low so findings should be interpreted with caution (82). A
772 larger synthesis of 17 observational studies reported generally favourable associations between
773 exposure to nature on children (0-12 years) and weight status (27). Of the 66 analyses, 68%
774 indicated improvements in obesity and/or overweight (27). Further evidence to understand the role
775 of nature-based ECE on **pre-school aged** children's weight status is needed, including the possible
776 mechanisms. For example, literature suggests that improvements in weight status is associated with
777 motor competence and physical activity (13, 17). There is also an evidence gap with no studies
778 included in the present systematic review exploring the role of nature-based ECE on children's diet
779 and nutrition; this may be an important area given that possible associations with physical activity,
780 sedentary time, or sleep would also have dietary impacts. Attention is also required on the impact of
781 nature-based ECE on other physical outcomes that have had limited or no attention in the eligible
782 studies (sleep, weight status, harms etc.).

783 It is important to note, that for some outcomes one might not expect to see a difference between
784 nature-based and traditional ECE as there might not be plausible mechanisms to suggest an added
785 value of exposure to nature resulting in an observed between group difference (for example, object
786 control, ball skills, manual dexterity, fitness).

787 **Strengths and limitations of the reviewed evidence**

A total of 39 unique studies reported a physical outcome, of which n= 6 studies were controlled before and after. These studies reflected a geographical spread of high income countries, including countries from North America, Europe, Australia, and Asia which ensure global relevancy of the review. Quantitative studies also tended to use valid and reliable measures for assessing outcomes and confounders were rated strong or moderate in 24/31 studies and qualitative studies demonstrated trustworthiness. However, no studies were conducted in low- or middle-income countries and three important factors limited our ability to draw conclusions on the findings: a) study quality, b) limited description of the exposure, and c) certainty of evidence.

Study quality was mostly impacted by two interconnected factors: a) most studies had a cross-sectional design (23/31) which means causal inference cannot be determined and b) most studies were rated weak (28/31). Based on the EPHPP Tool, the eligible studies were rated weak across the selection bias, blinding and attrition (before and after studies only) domains. For the study design domain, all cross-sectional studies were given a weak rating, uncontrolled before after were given a moderate rating, and controlled studies were given a strong rating. Furthermore, most studies did not report any formal power calculation (including identification of size of effect) and/or had small sample sizes, meaning that they may not have been adequately powered to detect changes.

The inconsistency and/or limited description of the **exposure** also limited out ability to draw conclusions. For example, for the physical activity outcome, one study did not explain the exposure or dose of nature the children received (58) and the other reported the control group received a weekly 2-hour "nature-based outdoor enrichment class" (47) – raising the question of potential dilution of programme effect on the outcome of interest (physical activity). These examples highlight an inherent problem across many of the included studies: the exposure and dose of nature received was inconsistently described, unclear, of indeterminate dose, or of potentially comparable level to their 'control' counterparts. In a recent narrative review by Holland and colleagues, they discussed limitations surrounding measurement of nature (83). The authors recommended that

future research must clearly describe the complexity of the nature exposure, including time spent in nature, frequency of visits, and quantifying the nature (e.g. amount of greenspace, types and number of trees etc.) (83). Given that health is impacted by nature through several possible mechanisms, describing the nature children are exposed to clearly (as above) will provide needed and important information on the specific pathways in which nature-based ECE is likely to impact on physical health outcomes (83).

Finally, **GRADE assessments** rated all evidence as very low as the absence of RCTs meant the start rating was low across all outcomes. In this field, it is unlikely that the "gold standard" RCT design could be used to evaluate the effect of nature-based ECE on child health outcomes. Therefore, despite following standard GRADE procedures, the certainty of evidence does not necessarily reflect the 'best available evidence' in the field more broadly. Furthermore, certainty of evidence with limited variation across outcome results makes it difficult to draw conclusions on the evidence. The challenges of applying GRADE to public health research has also been mentioned by Hilton-Boon and colleagues (84).

Strengths and limitations of the review process

At the development phase, a steering group of experts from policy, research and practice was created to ensure relevancy and rigour of the review. To capture as much relevant research, nine databases were searched and not limited by study design, publication year or language. Additional to published research, websites and grey literature were included in the search, and experts from policy, practice and research were contacted to provide evidence. The purpose of including this evidence and not only robust study designs was to ensure synthesis of the best evidence to date which is vital to informing future directions of the research. Both quantitative and qualitative evidence was considered in a mixed-methods evidence synthesis. This allowed us to better understand the phenomenon of nature-based ECE (qualitative studies) and to measure its magnitude, trends, and effects on physical development (quantitative studies) of children. Finally,

838 we followed a robust systematic review protocol, thus the risk of bias in our review methodology is
839 low.

840 Despite following strict systematic review procedures, the review also had a few limitations. Firstly,
841 given the large number of articles retrieved, title and abstract screening were not conducted in
842 duplicate. However, to mitigate this limitation a second reviewer checked 10% of the titles and
843 abstracts. Secondly, we made minor modifications to the EPHPP tool to define the target
844 population, specify confounders of interest and refining the overall rating of the paper to ensure the
845 tool was relevant to the present review.

846 **Future directions**

847 The current evidence base is limited by , weak study designs, nature exposure being poorly
848 described, and an understanding of which physical outcomes are of most importance to children
849 resultant from engaging with nature based-ECE (e.g. play and motor competence rather than
850 MVPA). These current limitations need to be addressed to help inform decision makers (e.g.
851 funding institutions such as local/national governments) to inform where investment in nature-based
852 ECE should be made.

853 To begin to understand the true impacts of nature-based ECE on children's physical health and
854 development, evidence needs to move towards controlled studies that are adequately powered to
855 detect changes in outcomes measured, factor important confounders (age, gender, SES, previous
856 exposure to nature) and assess attrition. If future studies addressed the inherent problems with **study**
857 **design** and **exposure** then the evidence base would be elevated allowing us to draw stronger
858 conclusions on whether nature-based ECE is, similar to or better than traditional ECE approaches.

859 Finally, it is likely that there are longer term impacts of attending nature-based ECE, however, long
860 term impacts were not assessed in eligible studies. This means we cannot draw firm conclusions on
861 what longer term outcomes may be or what the causal mechanisms by which possible outcomes

were improved. For example, as mentioned previously, we know from other evidence that motor competence and physical activity are associated which is likely to impact a child's weight status. Similar pathways could also be drawn between motor competence, physical activity and sleep as well as many other cognitive, social and emotional outcomes. However, to understand any of these longer-term benefits, we also need to understand if any possible benefits are sustained as children transition into primary/ elementary education where they may spend more time indoors in sedentary behaviour and with less exposure to nature.

Conclusions

Based on very low certainty of evidence, findings indicated inconsistent associations between nature-based ECE and children's sedentary time, MVPA, speed and agility, object control skills and illnesses. However, positive and consistent associations were found for balance. Consistent positive associations were also found between specific natural elements (e.g. vegetation) and different physical activity types (sedentary time, total physical activity, step counts and CPM). To enable stronger conclusions more high-quality evidence is needed where the nature exposure is adequately described and appropriate outcomes (e.g. different play types) are assessed over a longer duration. By building this evidence base we will be able to inform policy, practice and research whether nature-based ECE is equal to, or better than traditional ECE.

List of Abbreviations

ECE = Early childhood education

EPHPP = Effective Public Health Practice Project

ERIC = Education Research Information Centre

MVPA = Moderate-to-vigorous intensity physical activity

PI(E)COS = Population, Intervention or Exposure, Comparison, Outcomes and Study design

PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses

RCT = Randomised controlled trial

SES = Socioeconomic status

SWiM = Synthesis Without Meta-analysis

UV = Ultraviolet

GRADE = Grading of Recommendations Assessment, Development and Evaluation

Declarations

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AJ, AM, VW developed the search strategy in consultation with all authors. AJ, PM, AM, RC, IF, SI, FL, BJ, VW screened the articles. AJ, PM, AM, HT conducted quality appraisal and data extraction. AJ, PM, and AM drafted and revised the manuscript. All authors made substantial contribution to the conception of this work. All authors read and approved the manuscript. AM and PM take responsibility of the integrity of the work.

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Additional files

Additional file 1. Example search strategy for the MEDLINE database

Example search strategy for the MEDLINE database.

S1	(MH "Child, Preschool")
S2	TI child* OR AB child*
S3	TI (boy* OR girl*) or AB (boy* OR girl*)
S4	TI toddler OR AB toddler
S5	TI young N1 child* OR AB young N1 child*
S6	TI early N1 child* OR AB early N1 child*
S7	TI early N1 year* OR AB early N1 year*
S8	TI “pre-primary” or AB “pre-primary”
S9	S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8
S10	(MH "Schools, Nursery")
S11	TI nurser* OR AB nurser*
S12	(MH "Learning") OR TI early N1 learning OR AB early N1 learning
S13	TI (“preschool” or “pre-school”) OR AB (“preschool” or “pre-school”)
S14	TI kindergarten OR AB kindergarten
S15	TI (childcare OR child N1 care) OR AB (childcare OR child N1 care)
S16	TI (daycare OR day N1 care) OR AB (daycare OR day N1 care)
S17	(MH "Education") OR TI (education OR "preschool education" OR "outdoor education" OR "adventure education") OR AB (education OR "preschool education" OR "outdoor education" OR "adventure education")
S18	MM "Play and Playthings" OR TI (Play OR “play-based learning”) OR AB (Play OR “play-based learning”)
S19	TX (Waldkindergartens OR udeskole OR friluftsliv OR peuterspeelzaal OR kinderopvang OR bush N1 kinder*) OR TI (forest N1 kindergarten* OR forest N1 school*) OR AB (forest N1 kindergarten* OR forest N1 school*)
S20	S10 OR S11 OR S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19
S21	TI outdoor* OR AB outdoor*
S22	TI (nature OR “nature-based”) OR AB (“nature-based”)

S23	TI environment* OR TI outdoor N1 environment* OR AB outdoor N1 environment*
S24	TI (forest* OR wood* OR park* OR recreation* OR landscape* OR tree* OR hill* OR garden* OR beach* OR eco)
S25	AB (forest* OR wood* OR park* OR recreation* OR landscape* OR tree* OR hill* OR garden* OR beach* OR eco)
S26	TI (green OR greenspace or green N1 space) OR AB (green OR greenspace or green N1 space)
S27	TI (loose N1 parts OR "loose-parts") OR AB (loose N1 parts OR "loose-parts")
S28	TI (adventure* OR wild OR "open-air") OR AB (adventure* OR wild OR "open-air")
S29	S21 OR S22 OR S23 OR S24 OR S25 OR S26 OR S27 OR S28
S30	S9 AND S21 AND S30

Additional file 2. Modified quality appraisal tools for quantitative and qualitative studies

Modified Effective Public Health Practice Project (EPHPP) Quality Assessment Tool

Modifications highlighted in red text

A) SELECTION BIAS

(Q1) Are the individuals selected to participate in the study likely to be representative of the target population?

(i.e. children aged 2-7 years not in formal education yet)

1. Very likely
2. Somewhat likely
3. Not likely
4. Can't tell

(Q2) What percentage of selected individuals consented to the research?

1. 80 - 100% agreement
2. 60 – 79% agreement
3. less than 60% agreement
4. Not applicable
5. Can't tell

RATE THIS SECTION	STRONG	MODERATE	WEAK
See dictionary	1	2	3

B) STUDY DESIGN

Indicate the study design:

1. Randomized controlled trial
2. Controlled clinical trial
3. Cohort analytic (two group pre + post)

4. Case-control
5. Cohort (one group pre + post (before and after))
6. Interrupted time series
7. Other specify _____
8. Can't tell

Was the study described as randomized? If NO, go to Component C.

No **Yes**

If Yes, was the method of randomization described? (See dictionary)

No **Yes**

If Yes, was the method appropriate? (See dictionary)

No **Yes**

RATE THIS SECTION	STRONG	MODERATE	WEAK
See dictionary	1	2	3

C) CONFOUNDERS

(Q1) Were there important differences between groups prior to the intervention?

1. Yes
2. No
3. Can't tell

The following are examples of confounders:

1. Gender
2. Age
3. Socio economic status (SES – e.g. Parental education, deprivation status)

(Q2) If yes, indicate the percentage of relevant confounders that were controlled (either in the design (e.g. stratification, matching) or analysis)?

1. All confounders
2. Two confounders
3. One confounder
4. Can't Tell

RATE THIS SECTION	STRONG	MODERATE	WEAK
See dictionary	1	2	3

D) BLINDING

(Q1) Was (were) the outcome assessor(s) and/or analysists aware of the intervention or exposure status of participants?

1. Yes
2. No
3. Can't tell

(Q2) Were outcome assessors aware of the research question?

1. Yes

2. No
3. Can't tell

RATE THIS SECTION	STRONG	MODERATE	WEAK
See dictionary	1	2	3

E) DATA COLLECTION METHODS

(Q1) Were data collection tools shown to be valid?

1. Yes
2. No
3. Can't tell

(Q2) Were data collection tools shown to be reliable?

1. Yes
2. No
3. Can't tell

RATE THIS SECTION	STRONG	MODERATE	WEAK
See dictionary	1	2	3

F) WITHDRAWALS AND DROP-OUTS

(Q1) Were withdrawals and drop-outs reported in terms of numbers and/or reasons per group?

1. Yes
2. No
3. Can't tell
4. Not Applicable (i.e. one time surveys or interviews)

(Q2) Indicate the percentage of participants completing the study. (If the percentage differs by groups, record the lowest).

1. 80 -100%
2. 60 - 79%
3. less than 60%
4. Can't tell
5. Not Applicable (i.e. Retrospective case-control)

RATE THIS SECTION	STRONG	MODERATE	WEAK
See dictionary	1	2	3

COMPONENT RATINGS

Please transcribe the information from the grey boxes on pages 1-3 onto this page. See dictionary on how to rate this section.

A SELECTION BIAS	STRONG	MODERATE	WEAK
	1	2	3
B STUDY DESIGN	**STRONG**	**MODERATE**	**WEAK**

		1	2	3
C	**CONFOUNDERS**	**STRONG**	**MODERATE**	**WEAK**
		1	2	3
D	**BLINDING**	**STRONG**	**MODERATE**	**WEAK**
		1	2	3
E	**DATA COLLECTION METHOD**	**STRONG**	**MODERATE**	**WEAK**
		1	2	3
F	**WITHDRAWALS AND DROPOUTS**	**STRONG**	**MODERATE**	**WEAK**
		1	2	3

Overall Grade (based on above six criteria):

• Scored **1** for study design (i.e. controlled studies); AND
• Scored **1** or **2** in at least three other important components, including:
  ○ selection bias
  ○ confounders
  ○ blinding
  ○ withdrawals and drop-outs.
	STRONG
	1

• Scored **1** for study design; AND
• Scored **1** or **2** in two other important components, including:
  ○ selection bias
  ○ confounders
  ○ blinding
  ○ withdrawals and drop-outs.
 	
OR
 	
• Scored **2** for study design; AND
• Scored **1** or **2** in at least three other important components, including:
  ○ selection bias
  ○ confounders
  ○ blinding
  ○ withdrawals and drop-outs.
	MODERATE
	2

• Scored **1** for study design; AND
• Scored **3** in more than two other important components, including:
  ○ selection bias
  ○ confounders
  ○ blinding
  ○ withdrawals and drop-outs.
	WEAK
	3

OR
 	
• Scored **2** for study design; AND
• Scored **3** in more than one other important components, including:
  ○ selection bias
  ○ confounders
  ○ blinding
  ○ withdrawals and drop-outs.
 	
OR
• Scored **3** for study design	

1268

1269 **Dixon-Woods (2004) checklist**

1270 ***Modifications highlighted in red text***

Question 1	Are the research questions clear?
Question 2	Are the research questions suited to qualitative inquiry
Question 3	Are the following clearly described? - Sampling - Data collection - Analysis
Question 4	Are the following appropriate to the research question? - Sampling - Data collection - Analysis
Question 5	Are the claims made supported by sufficient evidence?
Question 6	Are the data, interpretations, and conclusions clearly integrated?
Question 7	Does the paper make a useful contribution to the review question?

Each question is answered either "yes", "no", or "can't tell".

1271

1272 **Additional file 3. Characteristics of included studies**
1273

Table 1. Characteristics of included quantitative studies						
Author, year and country	**Study design**	**Age (range or mean ± SD), sex (n or % m/f), SES.**	**Exposure and comparison**	**Follow-up time point**	**Outcome(s)**	**Data analysis**
Nature-based ECE						
Agostini et al (2018), Italy. E: 41 children / 7 teachers / 1 school C: 52 children / 13 teachers / 1 school	Controlled before & after	E: Age: 47.2 months ± 6.52 Gender: 13m/28f C: Age: 46.75 months ± 6.95 Gender: 29m/23f SES not reported.	E: Teachers underwent special training in outdoor education over one year including (15 days). ECE consisted of a green park with some centuries-old trees (e.g., firs, willows, maples), plants and flowers, and without any play structures. C: ECE contained grass and cement without larger plants, trees, and play structures.	T1= Jan 2014 T2= May 2014 T3= Oct 2014 T4= May 2015 (16 months from baselines)	Motor competence	Mixed-Model Repeated Measures analysis of variance (ANOVA)
Choi et al (2014), South Korea. E: 18 children / 1 ECE C: 19 children / ECE	Controlled before & after	E: Age: 4.2 ± 1.1 Gender: 11m/7f SES: all middle class C: Age: 4.0 ± 1.1 Sex: 11m/8f SES: all middle class	E: Children attend forest kindergarten 5 days per week, year-round, regardless of weather conditions. Children are outdoors more than 80% of the day and usually play, walk, run, and observe various things in the forest. C: Regular kindergarten (not described)	8 months	Sleep	Wilcoxon signed rank test.
Ene-Voiculescu & Ene-Voiculescu (2015), Fjortoft (2004), Fjortoft (2001), Norway.	Controlled before & after	Age: 6.1 years Gender: 38m/37f SES not reported.	E: Children used the forest every day for 1-2 hours throughout the year when they attended kindergarten. Occasionally they used the outdoor playground inside the kindergarten fence. The small forest (7.7 hectares) consisted of mixed woodland vegetation,	10 months	Motor competence	T-test.

E: = 46 children / 1 kindergarten C: 29 children, / 2 kindergartens			some open spaces of rocks and open fields and meadows in between. C: Children used the traditional outdoor playground for 1-2 hours a day and visited natural sites only occasionally.			
Müller et al (2017), Canada. E: 43 children / 1 ECE C: 45 children / 1 ECE	Controlled before & after	Age: E: 63.56 months (3.33 SD) C: 64 months (3.56 SD) Gender not reported. SES not reported.	E: "nature kindergarten" C: "traditional kindergarten" Neither are described.	9 months Sep/Oct-May	PA Motor competence	Analyses of Covariance (ANCOVA)
Frenkel et al (2019), USA. E: 71 children / 5 ECE C: 70 children / 4 ECE	Controlled cross-sectional	Age: 4.3% = 2 years, 29.1% = 3 years, 50.4% = 4 years, 16.3% = 5 years Gender: 82m/59f SES: 103, 036 USD (median zip code Income)	E: All nature ECE sites were located in parks with distinct areas marked off with rocks and other natural features for daily activities. Children were encouraged to play in the natural environment, which included grassy areas, areas with dirt, and tree cover and to play with natural features such as sticks, rocks, and mud. C: Traditional ECE were primarily held indoors and had outdoor play areas built on concrete. children spending less than 1.5 hr outdoors each day.	N/A	Harms	Poisson regression models Covariates: age
Fyfe-Johnson et al (2019), USA. E: 20 children / 1 ECE C: 13 children (waitlist control or 2-hour nature-based, outdoor	Controlled cross-sectional	Age: 3-5 years Gender: E: 11m/9f C: 9m/4f SES: E: 18 > $90,000 C: 8> $90,000	E: The nature ECE occurs outdoors in a forested park where most children attend 5 days per week from 9 am to 1 pm; 2-day and 3-day per week options are available on a limited basis. The physical environment consists of dedicated classroom areas in the forested areas. Children use logs and tree stumps to sit; portable canopies are used during inclement weather. Most of the day is	N/A	Physical activity	Descriptives only.

enrichment class provided by experimental ECE			spent hiking and exploring the surrounding forest. No traditional play structures or pre-fabricated playgrounds are utilized. C: 2 hour nature-based outdoor enrichment class was offered once weekly by the same nature ECE the intervention group children attended. Classes were led by a teacher and attended by both child and caregiver. The classes consisted of science-based exploration through outdoor play in a forested park and involved: circle time, station time (learning stations that emphasize sensory and fine motor skills, creativity, and numerical and literacy skills), short stories, and hikes. Others were included in a wait-list control			
Lysklett et al (2019), Norway. E: 43 children / 4 ECE C: 49 children / 4 ECE	Controlled cross sectional	Age: 5.1-6 years Gender: 53m/39f SES not reported	Nature-based ECEs located close to a large recreational area, with woods, lakes and tracks just outside the city centre. Both types of preschools used the nearby nature area for hiking and playing every week E: nature ECE at least three times, per week C: traditional preschools once per week.	N/A	Motor competence	T-test
Meyer et al (2017), Canada. E: 46 children / 3 ECE C: n= 35 children / 2 ECE	Controlled cross-sectional	Age: 5-6 years Gender: 39m/42f SES: predominately middle-class children	E: Children spent every morning in nature participating in teacher-directed, nature-based learning activities. The nature kindergartens differed per site but included a beach, unmanaged wooded area, natural playground (trees and vegetation) and artificial playground. C: Children were assessed in their classrooms where they engaged some storytelling, singing, dancing, tai chi, reading, drawing, and art. They also took part in music and computer classes and science fair.	N/A	PA	Descriptives only.

Moen et al (2007), Norway. E: 267 children / 37 ECE C: 264 children / 32 ECE	Controlled cross-sectional	Age: 3-6 years. Gender not reported. SES not reported.	E: had ‘‘outdoor’’ or ‘‘nature’’ as part of their name, or emphasized outdoor pedagogy and children spent an average of 3.5–8 hours/day outdoors in winter. C: children spend on average spend 1.25–4.0 hours/day outdoors.	N/A	Harms	GLM
Scholz & Krombholz (2007), Germany E: 45 children / 10 forest kindergartens C: Rural = 42 children / 2 ECE; Urban = 42 children / 2 ECE	Controlled cross-sectional	Age: E: 5.5 (SD 0.4) C: Rural= 5.7 (0.4 SD); Urban= 5.7 (0.4 SD) Gender: 71 boys, 58 girls SES not reported.	E: forest kindergarten C: traditional rural and urban kindergarten	N/A	Motor competence	MANOVA Covariates: age
Weisshaar et al (2006), Germany. E: 506 children / 25 ECE C: 1201 children / 28 ECE	Controlled cross-sectional	Age: 4.9 (1.1 SD) Gender: 901m/803f SES not reported.	E: Forest kindergarten located in forested areas where children spend all-season full-time outdoors. C: Conventional kindergartens (not described)	N/A	Harms	Fisher test and logistic regression Covariates: age, sex, skin inspection, and recommended vaccination
Ernst (2014), USA. E: 46 educators	Cross-sectional	Not described.	Outdoor environments that range from relatively natural to wild spaces.	N/A	Motor competence	Multiple regression
Wright (2019), USA. 48 children / 2 ECE	Cross-sectional	Age: 3-5 years Gender not reported. SES not reported.	The 2 sites were located in a forested park/ They both consisted of large space (10,000Sq/ft), log borders, sloping areas, vegetation, large trees, natural loose parts.	N/A	Physical activity	Descriptives only

			Manufactured supplies such as shovels, wheelbarrows, books, magnifying glasses were brought in. 4 hours of the school day is spent outdoors.			
ECE natural playgrounds						
Brussoni et al (2017), Canada. E: 48 children / 2 ECE	Uncontrolled before & after (mixed methods)	Age: 4.28 (0.63 SD) Gender: 53% m/47%f SES not reported.	Playgrounds were improved using the Seven Cs which consists of 27 items, rated on a 5-point scale, for a maximum score of 135 Changes predominately involved inclusion of more natural elements such as, vegetation, boulders, rock, loose parts. Seven Cs scores increased from 44 to 97 in ECE A, and 35 to 125 in ECE B.	Data were collected at T2; May-July 2014) two-weeks after playground modification	Physical activity	Wilcoxon signed rank tests; General linear modelling. Covariates: age, gender, ECE
Cosco et al (2014), USA. E: 804 / 27 ECE	Uncontrolled before & after	Age: 2-5 years Gender not reported. SES not reported.	Preventing Obesity by Design is an ECE outdoor renovation intervention. Prior to the intervention the space had few structures (slides, swings etc.) in a rectangle space enclosed by a fence. Whereas, post intervention, the space had more natural elements, including trees, garden, vegetation etc.	Not described.	Physical activity	Logistic regression and bivariate correlations Covariates: gender
Luchs, & Fikus (2018), Germany. E: 17 children / 1 ECE	Cross-sectional	Age: 5.85 ± 0.49 years Gender: 9m/8f SES not reported.	E: the nature playground has large natural space featuring trees, grass, hills, vegetations, water C: the contemporary playground has traditional play structures such as slides and swings. It has some natural elements, including grass and trees.	N/A	Physical activity	Paired sample t-test
Storli et al (2010), Norway. E: 16 children / 1 ECE	Cross-sectional	Age: 3-5 years Gender: 9m/7f SES not reported	Nature - gathering loose nature materials, climbing running. Traditional - children engaged in activities such as cycling, digging, climbing	N/A	Physical activity	t-tests

Torkar & Rejc (2017), Slovenia. E: 25 children / 1 ECE	Cross-sectional	Age: 4 and 5 years old Gender: 16m/9f SES not reported.	E: forest playground which contains a forest patch, river and bushes. The space is approx. 500 m^2 C: Traditional playground which contains fixed equipment such as seesaw, roundabout, slide, climbers and playhouse. There is some nature surrounding the playground (trees, bushes). The space is approx. 500 m^2	N/A	Physical activity	Mann Whitney
Natural elements within ECE						
Ng et al (2020), Australia. E: 159 children / 6 ECE C: 138 children / 5 ECE	Controlled before and after	Age: 2 years 10 months (0.82 SD) Gender: 49%m/51%f SES: No significant differences between intervention and control group reported.	Variable of interest was natural elements. Measured using the modified Environment and Policy Assessment and Observation (EPAO) physical environment domain. This tool assesses the prevalence of PA opportunities in the physical environment. There were 5 subscales: Fixed play equipment' and 'Portable play equipment' from the EPAO, 'Total size of playing area', 'Outdoor play spaces', and 'Natural elements'. A number of items per subscale were scored - 1 if present, 0 if not.	6 months	Physical activity	Mulitvariate linear regression Covariates: age, sex, parental education, accelerometer wear time.
Boldemann et al (2004), Sweden. E: 64 children / 2 ECE	Cross-sectional	Age: 1-6 years Gender:26m/38f SES not reported.	E: ECE 1 had play constructions surrounded by trees but exposed to the sun and ECE 2 had attractive play constructions positioned under a canopy of tree crowns. Average time spent outdoors was 207 min at site ECE 1, and 256 min at site 2.	N/A	UV exposure	t-tests
Boldemann et al (2006), Sweden. E: 199 children / 11 ECE	Cross-sectional	Age: 4.5-6.5 years Gender:114m/85f SES not reported.	ECE environment scores and averages dichotomized to (>2 high, <2 low) Outdoor environments were assessed on their play potential. They were scored 1, 2, and 3 with respect to size of outdoor area, overgrown surfaces (trees shrubbery) and integration of play structures or other defined play areas with vegetation.	N/A	Physical activity UV exposure	Bivariate analysis; Linear mixed-models.

Christian et al (2019), Australia. E: 678 children / 48 ECE	Cross-sectional	Age: 3.4 ± 0.8 Sex: 53%m/47%f SES: 32% = low, 34% = medium SES and 34% = high SES.	ECE settings were dichotomized to vegetation < 3m in height or vegetation> 3m in height. High-resolution airborne multispectral 4-band images and Geographic Information System (GIS) was used to identify the location, shape and size of ECE outdoor play spaces. Approximately 31% of centres' outdoor play space had vegetation with 23% (20.5 SD) having <3 m in height and 8% (13.7SD) with >3 m hight.	N/A	Physical activity UV exposure	Multilevel linear regression models. Covariates: age, gender, and ECE SES and size.
deWeger (2017), Australia. E: 274 children / 12 ECE	Cross-sectional	Age: 4.2 years (0.5 SD) Gender: 141m/133f SES not reported.	Variable = natural elements The quality of the outdoor learning environment in the ECE's was assessed for 3 hours per day over 2 days using the POEMS instrument. This is grouped into 5 domains: **Physical environment (13 questions),** Interactions (13 questions), Play and Learning Settings (13 questions), Program (9 questions), and Teacher/Caregiver role (8 questions). Scores are them summed to give a total score	N/A	Physical activity	Hierarchical linear modelling (HLM) Covariates: age, gender, BMI-z score and accelerometer wear time (level 1), outdoor environment quality (level 2)
Gubbels et al (2018), Netherlands. E: 151 children / 22 ECE	Cross-sectional	Age: 34.14 months (8.97 SD) Gender: 72m/79f SES not reported.	The SB and PA physical environment of each ECE was assessed using a standardized observation protocol, based on the updated Environment and Policy and Assessment Observation (EPAO). The following natural elements were assessed: large trees (2.5 m or taller), small trees (less than 2.5 m tall), trees that children can climb, shrubs, flowering plants, variation in ground	N/A	Physical activity	Multivariate linear regression analyses

			(hills, mounds), grass, rocks large enough to climb, a hill for rolling down or climbing up. A sum score of all the types of natural elements that were present was calculated.			
Määttä et al (2019), Finland. E: 864 children / 66 ECE	Cross-sectional	Age: 4 years 4 months (10 SD) Gender: 48% girls SES: 29% had mother with high educational background (at least masters)	Observation instrument was designed for the study and consisted of items from the EPAO. ECE physical environments were assessed, of which, surfaces in the preschool grounds (9 items) and terrain in the playground, related to the natural environment (grass, forest, trees, rocks).	N/A	Physical activity	Multilevel linear regressions models Covariates: age, gender, season, municipality, pre-school group cluster
Määttä et al (2019b), Finland. E: 655 children / 66 ECE	Cross-sectional	Age: 4.7years (0.89 SD) Gender: As above SES: As above	Frequency of nature trips (mean/per week): Teachers completed weekly diary of activities which were categorised into 5 groups (1=outdoors, 2=teacher-led sessions, 3=free play, 4=organised PA lessons and 5=mixed sessions). Daily number of each activity was calculated and summed for the week level and then divided by the number of the days (from 3 to 5) to form the average daily amount of each activity. A questionnaire was then completed to determine activities that are close to the ECE and occur regularly (nature visits). Visits were recorded for mean times per week	N/A	Physical activity	Multilevel linear regressions models. Covariates: age, gender, average attendance at preschool and study season
Olesen et al (2013), Denmark. E: 441 children / 42 ECE	Cross-sectional	Age: 5.8 years Gender: 49.5%m/50.5%f SES not reported.	Researchers collected a range of environmental correlates, of which, vegetation and hilly landscape related to nature	N/A	Physical activity	Univariate analyses and multi-level modelling

						Covariates: Gender, rain, preschool type, afternoon hours, location, indoor area, Playground area, playground time, parent education
Sando (2019), Norway. E: 80 children / 8 ECE	Cross-sectional	Age:3.5 (SD=0.5) Gender: 41m/39f SES not reported.	The places and materials in the playground were categorised into nature, pathways, open area and fixed functional equipment. Nature was coded in four of the institutions and ranged from large forest areas (1500 m^2) to smaller areas with trees and natural surfaces.	N/A	Physical activity	A random intercept multilevel model Covariates: age, gender
Sando & Sandseter (2019), Norway. E: 73 / 8 ECE	Cross sectional (mixed-methods)	Age: 4.2 years (0.7 SD) Gender: 36m/37f SES not reported.	ECE settings featuring nature were coded (places). For objects, these were coded when a child was holding, using or interacting with an object and included: sand, water, mud and nature materials The variables for places and objects describe the percentage of time the child is at a place or in which the object was used during each observation.	N/A	Physical activity	Generalized linear latent and mixed models
Söderström at al (2013), Sweden. E: 172 children / 9 ECE	Cross-sectional	Presented per ECE Age: S1: 4.6 (1.0 SD) S2. 4.1 (0.5 SD) S3: 4.3 (0.7 SD) S4: 4.4 (0.8 SD) S5: 4.7 (0.8 SD)	Outdoor Play Environment Categories (OPEC) scoring tool was used to assess playgrounds on (i) total outdoor area, (ii) amount of trees, shrubbery and hilly terrain and (iii) integration between vegetation, open areas and play structures, each component	N/A	Sleep Harms Weight status	ANOVA and MANOVA Covariates: Age, gender, birth Weight, mother SES.

		S6: 4.6 (0.9 SD) S7: 4.3 (0.9 SD) S8: 4.6 (0.6 SD) S9: 4.8 (0.7 SD) Gender: % f S1: 29% S2. 41% S3: 50 % S4: 42% S5: 50% S6: 56% S7: 61% S8: 41% S9: 63%	with a score range of 1–3 (high score = high quality). The OPEC scores were then dichotomized (low OPEC value< 2, high OPEC value >2)			
Sugiyama et al (2012), Australia. E: 89 children / 10 ECE	Cross-sectional	Age: 4.1 (0.6 SD) Gender: 54%m/46%f SES not reported	Questionnaire assessing characteristics of the ECE's was completed by the centre Director. Outdoor characteristics of relevance were gradient shade, vegetation, surface material (grass).	N/A	Physical activity	Multilevel linear regression Covariate: age, gender and time spent outdoors

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Table 2. Characteristics of included qualitative studies

Author, year and country	Age (range or mean ± SD), sex (n or % m/f), SES.	Exposure and comparison	Research aims	Data collection method	Details of analysis
Nature-based ECE					

Bjørgen (2016), Norway. 24 children / 1 ECE	Age: 3-5 years Gender: 10m/14f SES not reported.	Children played in the ECE outdoor play space for 3 hr/day, and each week would go on trips (1 or 2x) to natural environments. The large outdoor area consists of outdoor toys (buckets, shovels, trucks, balls), swings, sandboxes, climbing racks, natural materials, small trees, a varied surface of grass, sand, asphalt, and small hills. The destination for excursions in diverse natural landscape environment is approximately 300–700m from the centre. One type of natural environment was open fields suitable for tobogganing, running and playing on skis. Another natural environment consisted of woods. Trips were made to the natural environments all year round.	What is the relation between environmental affordances and PA levels among 3–5 year olds?	Observations were made with video recording the different seasons of the year for 20 days, 10 days on trips in a natural environment and 10 days in the centres play space. A total of 50 h of direct observation was conducted. Coding of the physical activity levels of children was assessed and adapted using the Observational System for Recording Physical Activity in Children-Preschool Version (OSRAC-P) manual.	Thematic analysis - the first phases of coding were assessing and identifying the children's level of PA in different play situations. Figures were used as an analytical tool helped to discern patterns, differences and similarities in the data material, which laid foundations for the qualitative analysis of the affordances. Thereafter themes of affordances are identified within the data. The theory of affordances and criteria from the 7Sc were used in the analysis process.
Dowdell et al (2011), Australia. E: 6 children / 1 ECE C: E: 6 children / 1 ECE	Age: 2-6 years Gender: 6m/6f SES not reported.	E: Has an emphasis on nature and sustainable education. The space is large and consists of sandpit, fairy garden, play equipment, grass area and vegetable garden. C: Located in a warehouse this centre has an entirely artificial indoor play area. It consists of a bike track, home corner (playhouse etc), climbing structures, quiet play area, sandpit and obstacle course.	How are children's play behaviours and social interactions influenced by the opportunities and materials present in their outdoor play environment?	Play behaviours were recorded using a behaviour mapping schedule. Each child was observed individually and every 10 seconds an observation based on social interaction and play behaviour was recorded.	Once all the observations were made for each child at each centre they were then tallied up. Play behaviours were then categorised into four different groups: social activities, cognitive activities, physical and motor skill activities and other activities.

Liu (2020), USA Nature interaction: E: 29 children / 1 ECE C: 26/ 1 ECE Restorative experiences: E: 10 children / 1 ECE C: 9 children/ 1 ECE	Age: 4-5 years Gender: 30m/ 25f SES: E: 48,000 US (household income); C: 59,000 (household income) of children attending each centre	E: contains high levels of nature with a variety of perceived affordances. Outdoor time = 1.5 hours/day. 32 types (categories- vegetation (tress, shrubs, flowers, grasses), natural ground surface (wood chips, meadow, multipurpose lawns), natural materials, natural play structures (e.g. wood, stick, water, sand logs, ice, leaves), animals, experiential elements (rain, snow, sky view, light, air) of natural elements and play settings and 4 types of non-nature-based play settings (concrete track, bicycles, concrete hall, concrete sq.) were identified C: low levels of nature and perceived affordances. Outdoor time = 1.5 hours/day. 13 types of natural elements and 11 (vegetation, natural ground, animals) types of non-nature-based play settings (examples include: play structure, playhouse, outdoor kitchen, bicycles) were identified.	How does the designed nature-based outdoor play environment in ECE impact children's interaction with natural elements? How does the designed nature-based outdoor play environment in ECE impact children's restorative experience?	RQ 1. Field observation, behaviour mapping, semi-structured interview with teachers. RQ2. Field observation, structured Interview with children, semi-structured interview with teachers.	Content analysis was used for: children's frequent play locations, types of play behaviors, frequency and diversity of different ways of interaction with natural elements, as well as restorative experience from semi-structured interviews with teacher and structured interview with children. Themes (coding categories) were drawn from the theoretical framework. Specifically, children's types of play behaviors and their ways of interacting with natural elements were coded using function taxonomy of affordance (Heft, 1988; Kyttä, 2002) and Gibson's affordance theory.
Sandseter (2009), Norway. 29 children from both experimental and control groups E: 1 ECE C: 1 ECE	Age: 4-5 years Gender: 21f/8m SES not reported.	E: Located in a forest with no fixed play equipment and fencing and children spent most of their time outdoors. C: fixed equipment, such as swings, climbing tower, play hut and a few trees.	To explore affordances for risky play in two different play environments: an ordinary ECE playground and a nature playground.	7 days were spent on each of the ECE playgrounds. Video recordings and field notes of risky play situations were collected based on categories of risky play; a) great heights, b) high speed c) dangerous tools, d) dangerous elements, e) rough-and-tumble play, f) where the children can disappear/get lost. Both the children's play and the staff's	A content analysis was performed on the data. The analysis was theory-driven. Firstly, each of the play environments' potential affordances for risky play, as categorized by Sandseter (2007), were analysed in relation to the most relevant affordance categories to evaluate their potential affordances for risky play.

				supervision were observed. The field notes and the video recordings were transcribed into an electronic word file. 12 children in the ordinary preschool and 11 children in the nature and outdoor preschool participated in a one-to-one qualitative interview with the researcher. Each interview was approximately 20-30 minutes and was recorded on audiotape. The interviews were semi-structured, using an interview guide list of questions and issues. The interview guide was based on the six categories of risky play and aimed to explore the types of risky play that the children engaged in within the different play environments and whether the staff constrained or intervened in their actions. Upon completion of the interviews, the audiotapes were professionally transcribed verbatim into an electronic word file.	Secondly, the transcriptions of the video observations, field notes, and interviews were examined to determine the types of risky play children engaged in within different environments. Thirdly, the observations and the interviews were analysed to determine the degree to which children experienced mobility license while engaging in risky play. The transcriptions of the video observations were examined to determine the extent to which, and in which situations, the staff had children under surveillance while they engaged in risky play or was taking initiative to or constrained risky play.
Streelasky (2019), Canada.	Age: 5-6 years Gender not reported.	The ECE setting had an outdoor, nature-based focus where children spent afternoons in the forested area. The teacher who was involved in an	What learning experiences do kindergarten children value at	Qualitative interpretative approach involving (i) group discussions, (ii) participant observations, (iii) anecdotal	Data were analysed and grouped into themes. Image based analysis was

15 children / 1 ECE	SES not reported.	Outdoor Environmental Leadership Programme engaged the students in an integrated learning approach where key curriculum areas were addressed (e.g. language arts, social studies, science and physical education). Children also had time to freely explore the forest.	school? and what modes are they choosing to express and represent their valued school learning experiences?	notes, (iv) artefact collection and (v) individual semi-structured interviews (children's narratives).	used to develop deeper understanding of children's interests and knowledge. Thematic analysis was used to gain insight into children's practices which followed 6 phases: (i) familiarising oneself with the data and identifying items of potential interest, (ii) generating initial codes, (iii) searching for themes, (iv) reviewing potential themes, (v) defining and naming themes and (vi) reporting the themes.
ECE natural playgrounds					
Herrington & Studtmann (1998), USA. 36 children / 1 ECE (2 "labs")	Age: 2-6 years Gender: 16m/20f SES not reported.	Pre-modification: Lab A: consisted of a patio area, grass lawn, play structures, swing set, doll house, trees and vegetation. Lab C consisted of a porch area, grass lawn, play areas, swing set, trees and vegetation. Post-modification: Playground were naturalised with increased natural elements: ice sculptures, wind chimes, canopy, chalk, buckets, playhouse, water pay, vegetation and trees were added to the labs.	What natural materials and conditions of the outdoor environment can contribute to the development of young children ranging from 2 to 6 years old?	Phase 1: sequence sampling of children during free-play. Children were video-taped interacting with the site for 1 month. Once the modifications were made, data collection began a week later. Data collection involved video-taping, sound recording, and field notes. Videotaping involved following a child for 20 minutes as they moved throughout the yard in free	20 hours of videotapes were analysed. During analysis, notes were made. For Phase 1 the notes were: (1) interaction with an intervention (2) duration of interaction (3) children's behavioural modification made between pre and post intervention (4) children's movement changes made between pre and post intervention. For Phase 2 the criteria were: (1) which children were engaged in the

		Lab A received more natural elements than lab C but both were more natural post intervention.		play. Voice recordings of the children were made of one of the two selected children from each Lab. Voice recordings were transcribed into text documents. Field notes (weather, teacher and children present, anecdotal observations etc.) were made daily by researchers. Notes were recorded by researchers on a pre-printed notation sheet that displayed a plan view of both yards. Phase 2: Video documentation and anecdotal notes were employed to record event sampling. Event sampling allowed subjects to be taped if they interacted with the plant interventions. The specific intervention sites were recorded on a rotating basis. Children were video-taped using the same schedule as in Phase 1 and fieldnotes were made in the same manner as in Phase I	intervention; (2) how many children were engaged (3) the duration and nature of their engagement with the intervention (4) how behavior and paths of movement changed between pre and post intervention. Video clips were selected that illustrated the notes. These clips were put together on one VCR tape using a television and VCR recorder. The conversations of the children participating in Phase 1 were transcribed at 10 second intervals. The anecdotal notes were reviewed and complied.
Puhakka et al (2019), Finland. 12-24 children (not clear) / 6 ECE	Age: 3-5 years Gender not reported. SES not reported.	Playground yards were transformed through enhancing the biodiversity by incorporating more greenspace and vegetation. For example, replacing areas covered in gravel with forest floor.	Does biodiversity exposure and greening playgrounds affect 3–5 years-old children's	Educators and child nurses completed interviews and surveys respectively. 49 parents completed surveys. Surveys were completed one month after the playground	Interviews were recorded and transcribed verbatim. Survey and interview data were analysed using qualitative content analysis to identify different affordances. The

		Children spent time outdoors every day (0.5–2 h in the morning and in the afternoon) as well as participating in teacher led activities 4-5 days/ week.	physical activity and play, their environmental relationships, and their well-being in the urban environment in Finland.	was modified. Surveys included both structured and open ended questions which related to children's play activities, and enthusiasm. Interviews with parents focussed on children perception of modifications. The educator thematic interviews focused on possible changes in children's play and other activities in the yard, in children's and educators' interest in and knowledge of nature, their well-being, attitudes towards outdoor activities, and practices and atmosphere in the ECE setting	affordances were then classified into 6 themes which emerged from analysis and coding. How these affordances supported children's relationship with the modified playground were then mapped. Finally, these two elements were brought together to form three perspectives.
Wishart et al (2019), Australia. 75 children / 1 ECE	Age:4-5 years Gender not reported. SES not reported.	The two playgrounds were located on different sides of the building, each extending to the back of the building where a connecting gate was sometimes opened to allow free-flow of children between the two spaces. E: Traditional equipment was replaced with terraces, inclines, logs and rocks designed to afford physical activities and gross motor skills such as climbing and balancing. other elements included: Natural gardens with fruit trees; herb garden and small plants; logs; stepping-stones; log enclosure; small tree forest; sandpit with pebbles and medium-size rocks.	Does the naturalised design of the new space provide equivalent actualisable affordances for different types of physical activity to those provided by the more traditional playspace, with its conventional equipment and resources	Behaviour mapping using a time-sampling observation tool. Observations were conducted between 10:30–15:30 during sessions. The two playscapes were divided into zones and children were observed in 3 minute cycles. For each observation, the tool also noted: number of boys and girls (no further count of children was taken); presence of educators; whether play was solitary or group; location and general contextual information.	Behaviour mapping tracked the incidence of different categories of movement across different areas of the two playscapes, to investigate if different categories of movement were more likely to occur in specific areas or in relation to specific features.

		C: standard equipment: slide, ladders, swings, climbing frames, sand-pit, surfaces open area. This area also included a grass area, veg garden, trees and shrubs.		40 observations in the naturalised space and 42 observations in the traditional space were made.	
Abbreviations: E= experimental; C= control; n= number; m=male; f= female; ECE = early childhood education (includes preschools, day care, kindergarten etc.); SES= socioeconomic status; PA= physical activity.					

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Study ID	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawals and drop-outs	Final Grade
Agostini et al (2018)	3 = Weak	1 = Strong	3 = Weak	3 = Weak	1 = Strong	3 = Weak	**3 = Weak**
Boldemann et al (2004)	3 = Weak	3 = Weak	1 = Strong	3 = Weak	1 = Strong	N/A	**3 = Weak**
Boldemann et al (2006)	2 = Moderate	3 = Weak	1 = Strong	3 = Weak	1 = Strong	N/A	**3 = Weak**
Brussoni et al (2017)	2 = Moderate	2 = Moderate	2 = Moderate	3 = Weak	1 = Strong	1 = Strong	**2 = Moderate**
Choi et al (2014)	3 = Weak	1 = Strong	2 = Moderate	3 = Weak	3 = Weak	1 = Strong	**2 = Moderate**
Christian et al (2019)	2 = Moderate	3 = Weak	1 = Strong	3 = Weak	1 = Strong	N/A	**3 = Weak**
Cosco et al (2014)	1 = Strong	2 = Moderate	1 = Strong	3 = Weak	1 = Strong	3 = Weak	**3 = Weak**
deWeger (2017)	2 = Moderate	3 = Weak	2 = Moderate	3 = Weak	1 = Strong	N/A	**3 = Weak**
Ene-Voiculescu & Ene-Voiculescu (2015), Fjortoft (2004), Fjortoft (2001)	3 = Weak	1 = Strong	1 = Strong	3 = Weak	1 = Strong	3 = Weak	**3 = Weak**
Ernst (2014)	2 = Moderate	3 = Weak	3 = Weak	3 = Weak	3 = Weak	N/A	**3 = Weak**
Frenkel et al (2019)	2 = Moderate	3 = Weak	1 = Strong	3 = Weak	1 = Strong	N/A	**3 = Weak**
Fyfe-Johnson et al (2019)	3 = Weak	3 = Weak	3 = Weak	3 = Weak	1 = Strong	N/A	**3 = Weak**
Gubbels et al (2018)	3 = Weak	3 = Weak	1 = Strong	3 = Weak	1 = Strong	N/A	**3 = Weak**
Luchs, & Fikus (2018)	3 = Weak	3 = Weak	1 = Strong	3 = Weak	1 = Strong	N/A	**3 = Weak**
Lysklett et al (2019)	3 = Weak	3 = Weak	2 = Moderate	3 = Weak	1 = Strong	N/A	**3 = Weak**
Määttä at al (2019)	3 = Weak	3 = Weak	2 = Moderate	3 = Weak	1 = Strong	N/A	**3 = Weak**
Määttä et al (2019)	3 = Weak	3 = Weak	2 = Moderate	3 = Weak	1 = Strong	N/A	**3 = Weak**
Meyer et al (2017)	3 = Weak	3 = Weak	3 = Weak	3 = Weak	3 = Weak	N/A	**3 = Weak**
Moen et al (2007)	2 = Moderate	3 = Weak	1 = Strong	3 = Weak	3 = Weak	N/A	**3 = Weak**
Müller et al (2017)	3 = Weak	1 = Strong	3 = Weak	3 = Weak	1 = Strong	1 = Strong	**3 = Weak**
Ng et al (2020)	3 = Weak	1 = Strong	1 = Strong	3 = Weak	1 = Strong	1 = Strong	**2 = Moderate**
Olesen et al (2013)	2 = Moderate	3 = Weak	1 = Strong	3 = Weak	1 = Strong	N/A	**3 = Weak**
Sando (2019)	2 = Moderate	3 = Weak	2 = Moderate	3 = Weak	1 = Strong	3 = Weak	**3 = Weak**
Sando & Sandseter (2019)	3 = Weak	3 = Weak	2 = Moderate	3 = Weak	1 = Strong	N/A	**3 = Weak**
Scholz & Krombholz (2007)	3 = Weak	3 = Weak	1 = Strong	3 = Weak	3 = Weak	N/A	**3 = Weak**
Söderström at al (2013)	2 = Moderate	3 = Weak	1 = Strong	3 = Weak	1 = Strong	N/A	**3 = Weak**
Storli et al (2010)	3 = Weak	3 = Weak	1 = Strong	3 = Weak	1 = Strong	N/A	**3 = Weak**

Sugiyama et al (2012)	3 = Weak	3 = Weak	2 = Moderate	3 = Weak	1 = Strong	N/A	**3 = Weak**
Torkar & Rejc (2017)	3 = Weak	3 = Weak	3 = Weak	3 = Weak	3 = Weak	N/A	**3 = Weak**
Weisshaar et al (2006)	2 = Moderate	3 = Weak	2 = Moderate	4 = Weak	1 = Strong	N/A	**3 = Weak**
Wright (2019)	3 = Weak	3 = Weak	3 = Weak	3 = Weak	3 = Weak	N/A	**3 = Weak**

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1281 **Additional file 5. Findings per eligible study**

1282

1283 **Quantitative**

Table 1. Nature-based ECE on physical activity								
Study details (Author, year and country) **Sample size** (n children / n ECE)	**Study Design**	**Outcome and measurement**	**Units**	**Baseline or one time point (cross-sectional)**	**Follow-up (if applicable) or mean difference**	**Summary of Findings**	**Effect Direction**	**Quality Rating**
Accelerometer								
Nature-based ECE								
Müller et al (2017), Canada. E: 43 children / 1 ECEs C: 45 children / 1 ECEs	Controlled before & after	SB and MVPA ActiGraph GT1M measured for 5 consecutive school days on three separate occasions: Oct (start of school yr), Jan and Apr (end of school yr). Cut points not described	SB (mins/ ECE day)	E: Oct= 167 Jan= 174 C: Oct= 178 Jan= 178	Apr= 151 Apr= 152	Within-group seasonal differences, but no between-group differences. (inferential statistics not provided)	▲	Weak
			MVPA (mins/ ECE day)	E: Oct= 74 Jan= 79 C: Oct = 79 Jan= 79	Apr = 68 Apr= 62	As above.	▲	
Fyfe-Johnson et al (2019), USA.	Controlled cross-sectional	PA and SB ActiGraph GT3X+ accelerometer worn for a minimum if 5 days (inc 1 weekend).	Habitual PA (mins/ day) SB Light	E: 467 (60 SD) C: 453 (51 SD)	Mead diff: 14.4, (95% CI: -29.1, 58.0) -10.1 (95% CI:	Children who attended nature-based ECE engaged in more SB, and less light PA and MVPA.	▼	Weak

E: 20 children / 1 ECEs C: 13 children (waitlist control or 2-hour nature-based, outdoor enrichment class provided by experimental ECEs		Weartime for total PA was 656 (59 SD), C= 667 (59 SD) Pate et al. (2006) cut points	 MVPA	E: 91.6 (13 SD) C: 102 (10 SD) E: 97.4 (16 SD) C: 113 (24 SD)	-19.2, -1.0) -15.5 (95% CI: -31.9, 0.87)			
			Habitual Weekday PA (mins/day) SB Light MVPA	 E: 468 (66 SD) C: 461 (54 SD) E: 93.5 (18 SD) C: 101 (15 SD) E: 97.1 (21 SD) C: 112 (30 SD)	 6.9 (95% CI: -40.1, 54.0) -7.3 (95% CI: -20.1, 5.4) -14.9 (95% CI: -36.3, 6.5)	As above.	▼	
			Habitual Weekend PA (mins/day) SB Light MVPA	 E: 486 (65 SD) C: 453 (51 SD) E: 88.7 (14 SD) C: 103 (15 SD) E: 95.8 (16 SD) C: 113 (22 SD)	 33.0 (95% CI: -14.8, 80.9) -14.2 (95% CI: -25.9, -2.4) -17.7 (95% CI: -33.8, -1.5)	As above.	▼	
			PA (mins/ ECE day – 9.00-13.00) SB Light	 E: 153 (19 SD) C: 166 (13 SD) E: 31.8 (11 SD) C: 32.7 (5 SD)	 -13.5 (95% CI: 63.3, 54.2) -0.9 (95% CI: -2.1, 0.64)	As above, but the differences in light PA and MVPA were much smaller.	▼	

			MVPA	E: 33.2 (15 SD) C: 34.7 (7 SD)	-1.5 (95% CI: -2.8, 1.2)			
			Sedentary bouts (ECE day) Bout, total number Bouts, number per day Bouts, total length Bout, average length	 E: 6.3 (3 SD) C: 6.4 (4 SD) E: 1.9 (1 SD) C: 2.0 (1 SD) E: 88.9 (47 SD) C: 100 (59 SD) E: 12.8 (5 SD) C: 16.1 (3 SD)	 -0.05 (95% CI: -2.9, 2.8) -0.11 (95% CI: -0.94, 0.73) -11.3 (95% CI: -54.4, 31.7) -3.3 (95% CI: -6.7, 0.13)	Children who attended nature-based ECE had similar total bouts and number of bouts per day to the control group. The bout total and average length were also higher in the control group.	▼	
ECE natural playgrounds								
Brussoni et al (2017), Canada. E: 48 children / 2 ECE	Uncontrolled before & after (mixed methods)	MVPA ActiGraph GT3X/GT3X+ worn during scheduled outdoor time (20 mins). Pate et al. (2006) cut points	MVPA (mins/ outdoor time)	Not presented.	- 1.32 min, 0.37 SE, p< 0.001	There was a significant decrease in time spent in MVPA from T1 to T2 across ECE's.	▼	Moderate
Luchs, & Fikus (2018), Germany. E: 17 children / 1 ECE	Cross-sectional	Gait cycles Microprocessor-based pedometer (StepWatch, Orthocare Innovations, Washington DC, USA) Worn twice for 45 minutes, once on the	Gait cycles/mins at playground	E: 25 (4.99 SD) C: 28.55 (9.60 SD) p= 0.109, d = 0.54)		No significant difference in mean gait cycles/min between the nature and traditional playground.	▼	Weak

		nature playground and once on the traditional playground.						
Storli et al (2010), Norway. E: 16 children / 1 ECE	Cross-sectional	CPM ActiGraph (model not described) Worn for three separate days over 6 months, including 2 days of outdoor activity on the pre-school playground (winter and spring) and one day in nature (spring). Wear time varied between 102–136 minutes Cut points not described,	Mean CPM	E: (spring) 1292 (307 SD) C: (spring) 1261 (426 SD) C: (winter) 1496 (475 SD) (p= 0.01)		There is an association between the levels of PA for the natural environment and traditional (spring and winter) playgrounds meaning PA levels are similar across the environments.	►	Weak
Torkar & Rejc (2017), Slovenia. E: 25 children / 1 ECE	Cross-sectional	Distance (km) Measured using GPS for 20 mins.	Distance (km)	E: 0.72 (0.49 SD) C: 0.49 (0.19 SD) (p= 0.132, r= 0.21)		There were no significant differences between the forest and traditional playground.	▲	Weak
Types of natural element								
Ng et al (2020), Australia. E: 159 children / 6 ECE	Controlled before and after	PA ActiGraph GTX3+ worn during ECE days ECE monitoring days were considered	Total PA min/ ECE day) MVPA min/ ECE day)	β= 14.46, p< 0.01 β= 10.04, p< 0.01		Natural grassed area was positively associated with Total PA and MVPA. Non-significant time x group interaction for natural elements on Total PA and MVPA	►	Weak

C: 138 children / 5 ECE		valid based on at least 1 day at ECE with 75% wear time Pate et al. (2006) cut points				(regression coefficients not presented)		
Boldemann et al (2006), Sweden. E: 199 children / 11 ECE	Cross-sectional	Step counts Yamax Digiwalker SW-200, MLS 2000 pedometer. Wear time not detailed.	Step counts/ min ECE day	High environment = 21.6 (95% CI: 20.6–22.5) Low environment = 17.7 (95% CI: 16.8–18.6) p<0.001		High environment score increased step count	▲	Weak
Christian et al (2019), Australia. E: 678 children / 48 ECE	Cross-sectional	Total PA Actigraph GT3TX+ Valid data included at least 1 day at ECE with 75% wear time. Data was averaged for children who attended more than 1 day during the 7-day monitoring period. Pate et al. (2006) cut points	Total PA (min/ ECE day)	% < 3m vegetation: β<-0.01 (95% CI: -0.22,0.21), p= 0.96) % > 3m vegetation: β = 0.02 (95%CI: -0.28, 0.32), p=0.89		Shade-related variables (vegetation < 3 metres in height and vegetation > 3 metres in height) were not significantly associated with minutes/day of total PA.	▲	Weak
			MVPA (min/ ECE day)	% < 3m vegetation: β = -0.01 (95% CI: -0.18, 0.16), p=0.91 % > 3m vegetation: β = 0.08 (95%CI: -0.16, 0.32), p=0.52		As above for MVPA	▲	

deWeger (2017), Australia. E: 274 children / 12 ECE	Cross-sectional	Total PA and MVPA (min/day at ECE), cpm and step counts Actigraph GT3X+ Accelerometers were worn for one ECE week (range of 1-5 days). Mean wear time was 390 minutes (87.4) or for 6.5 hours (1.5). Pate et al. (2006) cut points	Total PA (min/ ECE day)	intercept= 59.5, coefficient= 3.5, 1.8 SE, t= 1.89, p= 0.060		No significant association between setting with natural elements on total PA.	▲	Weak
			MVPA (min/ ECE day)	intercept= 10.3, coefficient= 1.7, 1.2 SE, t= 1.37, p= 0.17		As above for MVPA.	▲	
			Mean CPM / ECE day	intercept= 102000.5, coefficient= 4511.9, 5683.5 SE, t= 0.79, p= 0.43		As above for CPM.	▲	
			Step counts / ECE day	intercept= 2889.9, coefficient= 199.5, 89.8 SE, t= 2.22, p= 0.027		There was a positive association between settings with natural elements and step counts.	▲	
Gubbels et al (2018), Netherlands. E: 151 children / 22 ECE	Cross-sectional	SB, MVPA and CPM Actigraph GT3X+ Children were asked to wear the monitor for 7 consecutive days during their waking hours. Minimal wear time per day was 360 minutes and children had to have at least one valid ECE day to be included. Pate et al. (2006) cut points	Habitual SB %	β= −0.31, p< 0.001		Natural elements were significantly and positively associated with a reduction in percent time spent in SB	▲	Weak
			Habitual MVPA %	β= 0.27, p< 0.01		Natural elements were significantly and positively associated with an increased percent time spent in MVPA	▲	
			Habitual Mean CPM	β= 0.21, p< 0.01		Natural elements were significantly and positively associated with increased CPM.	▲	

Määttä et al (2019), Finland. E: 864 children / 66 ECE	Cross-sectional	Total PA Actigraph GT3X Worn for 7 days, 24-hours/day. A minimum wear time of 240 min during preschool hours was set. Evenson et al. (2008) cut points.	Total PA (min/hour in ECE)	Grass: β= 0.31, (95%CI: −0.84 - 1.46) Forest: β= −0.59, (95%CI: −1.87 - 0.69) Trees: β= --0.34, (95%CI: −2.13 - 1.45) Rocks: β= 0.01, (95%CI: −1.21 - 1.24)		There were no significant main or effect for grass, forest, trees or rocks	▲ ▼ ▼ ▲	Weak
Määttä et al (2019b), Finland. E: 655 children / 66 ECE	Cross-sectional	Sedentary Time As above.	Sedentary time (min/hour in ECE)	Frequency of nature trips β= −1.026 (95%CI: −1.804, −0.248), p= 0.010		Frequency of nature trips was associated with children's lower sedentary time.	▲	Weak
Olesen et al (2013), Denmark. E: 441 children / 42 ECE	Cross-sectional	MVPA ActiGraph accelerometer Children wore the monitors for 1 week.	MVPA (percent/ ECE day)	Vegetation: - 0.7; 95% CI: -1.3 to -0.0, p= 0.04)		The multilevel analysis showed that the daily percentage of MVPA was significantly negatively associated with vegetation	▼	Weak

		Minimum wear time was 3 pre-school days, with at least 3 hours of measurement. Median wear-time was 4 weekdays, 7.15 hours per day. Evenson et al. (2008) cut points.		Hilly landscape - 0.4; 95% CI: -1.1 to 0.2, p= 0.18.		The multilevel analysis showed that the daily percentage of MVPA was no association with hilly landscape.	▼	
Sugiyama et al (2012), Australia. E: 89 children / 10 ECE	Cross-sectional	MVPA and SB ActiGraph GT1M a Worn for 3 days at ECE. Minimum wear time was 2 days for at least 4 hours during the ECE day. Average wear time was 6 hours 40 minutes per ECE day. Sirard et al. (2005) cut points.	MVPA (min/ outdoor time)	Mostly natural surface: β= −5.8, (95% CI: −9.9, −1.7), p<0.01		Children attending ECE's with mostly natural surfaces were found to engage in significantly less MVPA compared with ECE with mostly "built" surfaces.	▼	Weak
				More vegetation: β= −1.2, (95% CI: −5.9, 3.5)		No association.	▼	
				Some gradient: β= 1.3, (95%CI: −4.5, 7.0)		As above.	▲	
				Much shade: β= 2.3, (95%CI: −3.5, 8.0)		As above.	▲	
			SB (min/ outdoor time)	Mostly natural surface: β= 8.0, (95% CI: −1.4, 17.4)		Natural surfaces, vegetation, gradient, and shade were not associated with SB.	▼	
				More vegetation: β= 2.3, (95% CI: −7.0, 11.6)			▼	
				Some gradient: β= −2.4, (95% CI: −13.7, 8.9)			▲	

				Much shade: β= −0.9, (95% CI:−12.6, 10.8)			▲	
Observational								
Nature-based ECE								
Meyer et al (2017), Canada. E: 46 children / 3 ECE C: 35 children / 2 ECE	Controlled cross-sectional	PA and PA types OSRAC-P Sampling Observation System which includes coding for body movements (stationary, slow-easy, moderate, and vigorous movements) and specific activity types (including climb, crawl, jump/skip, push/pull, rough and tumble, run, sit/squat, stand, throw, walk, and other). 2 students were observed at a time for 30-second intervals (5 sec observation, 25 sec coding). Observations occurred every 30 seconds for a period of 5 minutes which resulted in 20 observations. This was then repeated.	PA frequencies: Stationary Slow-easy Moderate Vigorous	 E:0.56 (0.15 SD) C: 0.84 (0.02 SD) E:0.30 (0.08 SD) C: 0.16 (0.02 SD) E:0.12 (0.08 SD) C: 0 (0 SD) E: 0.02 (0 SD) C: 0 (0 SD)		Children in the nature kindergarten were less stationary and engaged in more slow-easy and moderate physical activity compared to the control ECE.	N/A	Weak
			PA types: (frequencies) Sit/Squat Walk Stand Fine Motor Eat	 E: 0.19 (0.13 SD) C: 0.53 (0.09 SD) E: 0.17 (0.02 SD) C: 0.06 (0.01 SD) E: 0.14 (0.08 SD) C: 0.16 (0 SD) E: 0.14 (0.06 SD) C: 0.12 (0.09) E: 0.08 (0.03 SD) C: 0 (0 SD)			N/A	

			Lie Down Push/Pull Rough & Tumble Run Climb Jump Throw Crawl Balance Other	E: 0.01 (0.01 SD) C: 0 (0 SD) E: 0.01 (0.01 SD) C: E: 0 (0 SD) C: 0 (0 SD) E: 0.04 (0.02 SD) C: 0 (0 SD) E: 0.10 (0.07 SD) C: 0 (0 SD) E: 0 (0 SD) C: 0 (0 SD) E: 0.01 (0.01 SD) C: 0 (0 SD) E: 0.01 (0.01 SD) C: 0.01 (0.01 SD) E: 0.05 (0.04 SD) C: 0.01 (0.01 SD) E: 0.05 (0.02 SD) C: 0.10 (0 SD)				
Wright (2019), USA. 48 children / 2 ECE	Cross-sectional	PA Children were observed and recorded over 2 school years. A randomised time sampling protocol was used with 10 min intervals at five zones.	overall frequency / relative frequency (% each type of activity was out of total instances of all PA)			"manipulation" was the most frequent PA type observed. balance, run, sit stand and squat were less frequent.	N/A	Weak

		A sub-sample of the recordings was taken and coded at the 0:00, 1:00 and 2:00 mark for 20-second intervals. An adapted version of (OSRAC-P) was used to code the PA types.	Balance: Climb: Dig/Rake: Jump/Skip: Lie Down: Manipulation: Push/Pull: Resistive: Run: Sit: Stand: Squat: Throw: Walk:	34 / 7% 22 / 5% 19 / 4% 29 / 6% 9 / 2% 107 / 23% 21 / 4% 28 / 6% 34 / 7% 33 / 7% 38 / 8% 44 / 9% 16 / 3% 16 / 3%				
ECE natural playgrounds								
Cosco et al (2014), USA. E: not clear / 27 ECE	Uncontrolled before & after	PA Children's Activity Rating Scale (CARS) CARS allows trained observers to record children's PA on a five-point scale: 1) stationary or motionless, 2) stationary with limb or trunk movements, 3) slow-easy, 4) moderate, and 5) fast.	PA		Unstandardised (standardised effects) 0.113 (0.067), p= 0.001	At post-intervention there was an effect on children's PA.	▲	Weak
			Non sedentary PA		0.202 (1.22), p= 0.001	As above for non-sedentary PA.	▲	
			MVPA		0.061 (1.063), Non-sig	Non-significant	▲	
Natural elements within ECE								
Sando (2019), Norway.	Cross-sectional	PA Observational System for Recording PA in Children-Preschool (OSRAC-P)	PA (1-5)	3.2 (0.9 SD), (regression coefficient= 0.004)		Nature was not a statistically significant predictor of PA.	▲	Weak

E: 80 children / 8 ECE		PA is coded from 1 (stationary) to 5 (fast movement). 2 children were filmed per day. The 1st for 2 minutes followed by a 6-minute break, then the 2nd child. Filming alternated between each child until 6 video observations of each child were recorded. 480 video clips in the outdoor environment constituted a full sample. There was a total of 471 video clips in the final analysis.						
Sando & Sandseter (2019), Norway. E: 73 / 8 ECE	Cross sectional (mixed-methods)	PA and wellbeing (combined outcome) Wellbeing - Leuven Wellbing Scale measures wellbeing on a scale 1 (extremely low) -5 (extremely high). A score of 1 is when children exhibit high levels of discomfort (whining, screaming, sadness) and 5 is clear signs of happiness, relaxed and lively. Physical activity: see above, OSRAC-P	PA and wellbeing	Nature: No association Sand: b =−0.027, (95% CI =−0.043–0.011), p= 0.001. Nature materials: b =−0.008, (95% CI =−0.015–0.001), p= 0.028. Water: no association Mud: no association		Nature is not associated with observations with high wellbeing and PA.	▼	Weak

		which codes PA from 1 (stationary) to 5 (fast-movement).						

Abbreviations: E= experimental; C= control; n= number; ECE = early childhood education (includes preschools, day care, kindergarten etc.); PA= physical activity; MVPA= moderate to vigorous PA; SB= sedentary behaviour; CPM= counts per minute; Yr= Year; min = minutes; SD= standard deviation; SE= standard error; CI= confidence intervals.

Effect direction explained:
▲: positive association
►: no change/ conflicting findings
▼: negative health association
▲: positive association and statistical significance ($p<0.05$)
▼: negative association and statistical significance ($p<0.05$)
No arrow: no inferential statistics reported

Controlled before & after studies – difference between experimental and control group at follow-up (unless stated) or difference in change between experimental or control group. Uncontrolled before & after studies – change since baseline (unless stated). Controlled cross sectional – difference between experimental and control (unless stated). Cross-sectional – positive, negative or no association

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Table 2. Nature-based ECE on motor competence

Study details (Author, year and country) **Sample size** (n of children / n ECE settings for exp and con)	**Study Design**	**Outcome and measurement**	**Units**	**Baseline or one time point (cross-sectional)**	**Follow-up (if applicable) or mean difference**	**Summary of Findings**	**Effect Direction**	**Quality Rating**
Nature-based ECE								
Agostini et al (2018), Italy.	Controlled Before & After	Body function, gross motor skills and fine motor skills	Body Function	T1 (Jan 2014) E:11.02 (0.81 SD) C:10.15 (1.03 SD)	T4 (May 2015) 12.81 (0.71 SD) 12.39 (1.24 SD)	There was a significant time x group interaction on	▲	Weak

E: 41 children / 7 teachers / 1 school C: 52 children / 13 teachers / 1 school		Kuno Beller Developmental Tables completed by educators which assesses development in 8 developmental areas: Body Function, Awareness of the Surrounding Environment, Social and Emotional Development, Play, Language, Cognitive Development, Gross and Fine Motor Skills.			p= 0.010; ηp^2= 0.27	children's body function. There were no significant differences between groups at T4.		
			Gross Motor Skills	E:11.79 (1.01 SD) C:10.87 (0.91 SD)	13.32 (0.80 SD) 12.96 (1.07 SD) p= 0.021; $\eta p2$= 0.24	As above.	▲	
			Fine Motor Skills	E:10.86 (0.76 SD) C:10.01 (1.34 SD)	12.73 (0.88 SD) 12.56 (1.28 SD) p= 0.000; $\eta p2$= 0.15.	As above.	▲	
Ene-Voiculescu & Ene-Voiculescu (2015), Fjortoft (2004), Fjortoft (2001), Norway. E: = 46 children / 1 kindergarten	Controlled Before & After	Motor fitness The EUROFIT Physical Fitness Test which consists of: flamingo balance test (standing on 1 foot - balancing); plate tapping (tapping of 2 plates alternatively-speed of limb movement); sit and reach (flexibility); standing broad jump (jumping for distance from a standing start –	Flamingo balance test / n of instabilities in 30 secs	E: 4.7 (0.8 SE) C: 4.0 (0.6 SE)	E: 1.5 (0.3 SE), p<0.001 C: 3.3 (0.7 SE)	At post-test, there were significant differences in the intervention group compared to the control group in the Flamingo balance test (p< 0.001).	▲	Weak
			Plate tapping / time in secs for 50 taps	E: 35.0 (1.9 SE) C: 29.9 (1.1 SE)	E: 28.1 (1.2 SE), p<0.001 C: 27.4 (2.6 SE)	No significant differences at post-test.	▼	
			Sit and reach / cm	E: 24.9 (0.8 SE) C: 25.3 (1.0 SE)	E: 24.4 (0.8 SE) C: 25.5 (0.9 SE)	As above.	▼	

C: 29 children, / 2 kindergartens		explosive strength); sit-ups (max n of sit-ups in 30 secs); bent arm hang (from a bar- functional strength); shuttle run (running and turning, shuttle - speed and agility) Beam walking to test dynamic balance and Indian skip (clapping right knee with left hand and vice versa - coordination), which were added.	Standing broad jump / cm	E: 102.8 (2.9 SE) C: 103.1 (4.3 SE)	E: 113.1 (3.6 SE), p<0.001 C: 111.3 (3.8 SE), p<0.01	As above.	▲	
			Sit-ups / reps.30 secs	E: 5.3 (0.6 SE) C: 5.9 (0.8 SE)	E: 6.5 (0.6 SE) p<0.01 C: 7.0 (1.1 SE)	As above.	▼	
			Bent arm hang / sec	E: 2.6 (0.4 SE) C: 2.6 (0.6 SE)	C: 7.0 (1.0 SE), p<0.001 C: 5.4 (1.1 SE), p<0.001	As above.	▲	
			Beam walking / sec	E: 11.4 (1.4 SE) C: 7.7 (0.8)	E: 7.5 (0.7 SE), p<0.01 C: 7.2 (1.1 SD)	As above.	▼	
			Indian skip / reps.30 secs	E: 21.8 (2.2 SE) C: 27.8 (2.4 SE)	E: 43.6 (1.9 SE), p<0.001 C: 37.2 (1.8 SE), p<0.001	At post-test, there were significant differences in the intervention group compared to the control group in the Indian skip co-ordination test (p< 0.01).	▲	
			Shuttle run run/sec	E: 31.9 (0.7 SE) C: 30.7 (0.8 SE)	E: 29.7 (0.5 SE), p<.01 C: 30.3 (0.7 SE)	No significant differences at post-test.	▲	

Müller et al (2017), Canada. E: 43 children / 1 nature-kindergarten C: 45 children / 1 traditional kindergarten	Controlled before & after	Perceived physical competence, and locomotor and object control skills. Subscale of the Pictorial Scale of Perceived Competence and Social Acceptance for Young Children (six items) - children were asked to indicate who they are more like based on two descriptions of children (one competent and one not). Each item was scored on a four-point scale, where 4 indicates a high degree of perceived competence and 1 indicates a low score. TGMD-2 - assesses 6 locomotor and 6 object control skills. Scored either 1 or 0 depending on whether component was performed correctly.	Perceived Physical Competence	E: 18.72 (0.47 SE) C: 18.58 (0.44 SE)	E: 19.03 (0.48 SE) C: 19.47 (0.44 SE) p= 0.45, η2= 0.01	At post-test there was a small and non-significant effect	▼	Weak
			Locomotor skills	E: 24.68 (1.01 SE) C: 24.61 (0.94 SE)	E: 28.03 (0.82 SE) C: 25.72 (0.80 SE) p= 0.03, η2= 0.06	At post-test there was a moderate and significant effect	▲	
			Object control skills	E: 21.71 (0.98 SE) C: 23.05 (0.91 SE)	E: 23.97 (0.89 SE) C: 23.05 (0.91 SE) p= 0.15, η2= 0.03	At post-test there was a small and non-significant effect	▲	
Lysklett et al (2019), Norway. E: 43 children / 4 preschools	Controlled cross sectional	Motor competence Assessed using the Movement Assessment Battery (MABC-2). The test includes 8 subtests divided into 3	Manual dexterity	E: 3.72 (2.99 SD) C: 3.29 (2.67 SD)	Mean difference 0.43 (95% CI: −0.74–1.59), p= 0.498	No significant differences in scores between the nature and traditional preschools	▼	Weak

C: 49 children / 4 preschools		categories: 1) manual dexterity (posting coins, threading beads and drawing a line into a trail), 2) ball skills (catching beanbag and rolling ball into goal), and 3) static and dynamic balance (one-leg balance, walking heel raised and jumping over cord). Children are scored from 0-5. The total score sums the eight tests with a score of 0 the best and 40 the poorest.	Ball Static and dynamic balance Total	E: 2.60 (2.34 SD) C: 2.41 (1.67 SD) E: 1.08 (1.71 SD) C: 0.94 (1.58 SD) E: 7.41 (4.91 SD) C: 6.64 (3.72 SD)	0.20 (95% CI: −0.64–1.03), p= 0.641 0.14 (95% CI: −0.53–0.82), p= 0.678 0.76 (95% CI: −1.03–2.56), p= 0.399	for total and subtest scores.		
		The assessment for fitness consisted of 9 subtests: standing broad jump, Jumping on two feet, Jumping on one foot, Throwing a tennis ball (m), Putting a medicine ball, Climbing wall bars, Shuttle run, 20 m sprint, Reduced Cooper test. A total test score was calculated and transformed into z-scores (standardized scores).	Standing broad jump (cm) Jumping on two feet (s) Jumping on one foot (s) Throwing a tennis ball (m)	E: 94.78 (14.07 SD) C: 97.63 (15.59 SD) E: 6.16 (3.58 SD) C: 5.18 (1.61 SD) E: 5.48 (2.19 SD) C: 4.85 (1.19 SD) E: 6.00 (2.17 SD) C: 6.21 (1.88 SD)	Mean difference −2.86 (95% CI: −9.26–3.55), p= 0.378 0.98 (95% CI: −0.22–2.18), p= 0.108 0.63 (95% CI: −0.22–1.49), p= 0.144 −0.21 (95% CI: −1.06–0.64), p= 0.623	Children attending the traditional preschools performed better in the shuttle run, reduced Cooper test and the total score compared to the nature playground. The rest were non-significant.	▼ ▼ ▼ ▼	

			Putting a medicine ball (m)	E: 1.88 (0.49 SD) C: 1.96 (0.43 SD)	−0.08 (95% CI: −0.27–0.11), p= 0.379		▼	
			Climbing wall bars (s)	E: 32.32 (14.60 SD) C: 31.21 (11.38 SD)	1.11 (95% CI:−4.37–6.59), p= 0.688		▼	
			Shuttle run (s)	E: 31.40 (3.96 SD) C: 30.00 (2.45 SD).	1.40, 95% CI: 0.05–2.74, p= 0.043		▼	
			20 m sprint (s)	E: 5.66 (0.48 SD) C: 5.53 (0.57 SD)	0.13 (95% CI: 0.13 – −0.08), p= 0.232		▼	
			Reduced Cooper test (m)	E: 740.09 (120.44 SD) C: 817.56 (105.32 SD)	77.47, 95% CI: −124.22– −30.71, p= 0.001),		▼	
			Total test score (z)	C: −0.12 (0.65 SD) E: 0.17 (0.57 SD)	0.29, 95% CI: −0.55– −0.04, p= 0.025		▼	
Scholz & Krombholz (2007), Germany	Controlled cross-sectional	Fundamental movement skills (test not described) Consisted of the following domains:	Balancing forward (n of correct steps)	E:22.5 (1.7 SD) C (R): 20.5 (3.5 SD) C (U): 19.4 (3.6 SD) p<0.000		There was a significant higher performance in forest nurseries vs conventional rural and urban nurseries for balancing forwards and	▲	Weak

E: 45 children / 10 forest kindergartens C: Rural = 42 children / 2 ECE; Urban = 42 children / 2 ECE		balancing forward (balance); balancing backward (balance); jumping left and right; (coordination, speed); long jump; (coordination, speed); jumping forwards on one leg (coordination, endurance); hanging on pull up bar (strength endurance); shuttle run (speed, coordination)	Balancing backward (n of correct steps)	E: 51.5 (10.1 SD) C (R): 39.9 (10.9 SD) C (U): 35.5 (14.3 SD) p<0.000		backwards, hanging on pull up bar, jumping left/right, shuttle run and one-leg jump forward on left.	▲	
			Jumping left and right (n of jumps)	E: 29.9 (6.0 SD) C (R): 31.1 (7.3 SD) C (U): 27.0 (7.1 SD) p=0.012			►	
			Long jump (distance in cm)	E: 94.0 (16.1 SD) C (R): 102.4 (18.4 SD) C (U): 94.0 (18.7 SD)			►	
			Hanging on pull up bar (time in seconds - max 30 sec)	E: 25.6 (6.2 SD) C (R): 20.7 (7.7 SD) C (U): 19.7 (7.0 SD) p<0.000			▲	
			Shuttle run (time in seconds)	E: 9.6 (1.2 SD) C (R): 9.1 (0.8 SD) C (U): 10.2 (1.5) p<0.000			▼	
			Jumping forwards on one leg (n of jumps on each leg – max 20)	Right: E: 17.5 (4.4 SD) C (R): 17.2 (4.9 SD)			▲	

				C (U): 16.0 (6.0 SD) Left: E: 17.8 (4.5) C (R): 16.8 (5.3), C (U): 14.1 (6.8) p=0.007			▲	
Ernst (2014), USA. E: 46 educators	Cross-sectional	Physical development Questionnaire (not described) on importance of natural outdoor settings on children's cognitive, social, and physical development and their appreciation for the environment. Responses were provided on a five-point scale, ranging from one (strongly disagree) to five (strongly agree)	Physical development (1-5)	4.39 (1.31 SD), r= 0.05		Educators agreed that experiences in natural settings were important for children's physical development. There was no association between frequency of nature experiences and belief regarding importance of outdoor settings for physical development.	▲	Weak

Abbreviations: E= experimental; C= control; n= number; ECE = early childhood education (includes preschools, day care, kindergarten etc.); SD= standard deviation; SE= standard error; CI= confidence intervals; cm= centimetres; sec= seconds; R= rural; U= urban

Effect direction explained:
▲: positive association
►: no change/ conflicting findings
▼: negative health association
▲: positive association and statistical significance ($p<0.05$)
▼: negative association and statistical significance ($p<0.05$)
No arrow: no inferential statistics reported

Controlled before & after studies – difference between experimental and control group at follow-up (unless stated) or difference in change between experimental or control group. Uncontrolled before & after studies – change since baseline (unless stated). Controlled cross sectional – difference between experimental and control (unless stated). Cross-sectional – positive, negative or no association

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Table 3. Nature-based ECE on weight status

Study details (Author, year and country) **Sample size** (n of children / n ECE settings for exp and con)	**Study Design**	**Outcome and measurement**	**Units**	**Baseline or one time point (cross-sectional)**	**Follow-up (if applicable) or mean difference**	**Summary of Findings**	**Effect Direction**	**Quality Rating**
Natural elements within ECE								
Söderström at al (2013), Sweden. E: 172 children / 9 ECEs	Cross-sectional	BMI Weight = digital scale, height = measuring tape	BMI	Low OPEC Overweight= 16% Normal weight= 82% High OPEC Overweight= 7% Normal weight= 87% p= - 0.07		Outdoor environment quality was not significantly associated with BMI or waist.	▲	Weak
		Waist Measuring tape	Waist (cm)	Low OPEC: 52.6 (3.5 SD) High OPEC: 52.2 (3.5 SD) p= 0.25			▲	

Abbreviations: E= experimental; C= control; n= number; ECE = early childhood education (includes preschools, day care, kindergarten etc.); SD= standard deviation; BMI= body mass index; cm= centimetres; OPEC= outdoor Play Environmental Categories

Effect direction explained:
▲: positive association
►: no change/ conflicting findings
▼: negative health association
▲: positive association and statistical significance ($p<0.05$)
▼: negative association and statistical significance ($p<0.05$)
No arrow: no inferential statistics reported

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1286

Table 4. Nature-based ECE on Sleep

Study details (Author, year and country) **Sample size** (n of children / n ECE settings for exp and con)	**Study Design**	**Outcome and measurement**	**Units**	**Baseline or one time point (cross-sectional)**	**Follow-up (if applicable) or mean difference**	**Summary of Findings**	**Effect Direction**	**Quality Rating**
Nature-based ECE								
Choi et al (2014), South Korea.	Controlled Before & After study	Sleep Parents competed the CSHQ which consists of 33 items with a 3 point scale, "usually (5–7 times a week)",	Total score of CSHQ	E: 51.6 ± 8.2 C: 55.6 ± 6.6	E: 47.7 ± 5.7, p= 0.02 C: 55.8 ± 6.5, p= 0.92 Between group: p< 0.01	After post-test, the CSHQ total score, sleep disordered breathing and daytime sleepiness were significantly lower in children from the forest	▲	Moderate

E: 18 children / 1 ECE C: 19 children / ECE		"sometimes (2–4 times a week)", and "rarely (0–1 time a week)". This questionnaire consists of 8 domains: bedtime resistance, sleep onset delay, sleep duration, sleep anxiety, night wakings, parasomnia, sleep-disordered breathing, and daytime sleepiness. These domain scores are accumulated for a total CSHQ Score. Total sleep time was also reported.	Total sleep time (hours)	E: 10.5 ± 1.1 C: 10.7 ± 1.1	E: 10.5 ± 1.0, p= 0.68 C: 10.4 ± 0.9, p= 0.21	kindergarten program compared with the regular kindergarten program. There was no significant difference in total sleep time or other sub-scales.	▲	
			Bedtime resistance	E: 11.8 ± 2.6 C: 12.7 ± 2.5	E: 11.3 ± 2.4, p= 0.34 C: 12.8 ± 2.2, p= 0.98		▲	
			Sleep onset delay	E: 1.3 ± 0.6 C: 1.2 ± 0.5	E: 1.2 ± 0.4, p= 0.08 C: 1.4 ± 0.7, p= 0.36		▲	
			Sleep duration	E: 3.7 ± 1.1 C: 4.1 ± 1.4	E: 3.3 ± 0.6, p= 0.13 C: 3.7 ± 1.3, p= 0.37		▲	
			Sleep anxiety	E: 7.1 ± 2.0 C: 7.4 ± 1.8	E: 6.5 ± 2.0, p= 0.28 C: 7.5 ± 1.5, p= 0.84		▲	
			Night wakings	E: 3.6 ± 0.8 C: 3.6 ± 0.8	E: 3.5 ± 0.4, p= 0.71 C: 3.6 ± 1.0, p= 0.99		▲	
			Parasomnia	E: 9.2 ± 2.0 C: 10.0 ± 1.8	E: 8.6 ± 1.5, p= 0.11 C: 9.3 ± 1.9, p= 0.12		▲	
			Sleep disordered breathing	E: 3.3 ± 0.6 C:3.4 ± 0.8	E: 3.1 ± 0.5, p= 0.16 C: 3.7 ± 1.0, p= 0.10		▲	

			Daytime sleepiness	E: 11.6 ± 2.5 C: 13.3 ± 2.9	Between group: p= 0.04 E: 9.8 ± 1.0, p= 0.02 C: 13.7 ± 3.5, p= 0.52 Between group: p< 0.01		▲	
Natural elements within ECE								
Söderström at al (2013), Sweden. E: 172 children / 9 ECE	Cross-sectional	Sleep A sleep diary was completed for one week by the children's parents. Parents recorded the time the children woke up and the time they went to sleep. Sleep time was calculated as a mean of the seven days.	Mean sleep time (minutes)	Low OPEC (n= 103): 642 (32 SD) High OPEC (n= 66): 658 (44 SD) p= 0.03		Outdoor environment quality was significantly associated with night sleep (p = 0.03)	▲	Weak

Abbreviations: E= experimental; C= control; n= number; ECE = early childhood education (includes preschools, day care, kindergarten etc.); CSHQ= Children's Sleep Habits Questionnaire; OPEC= outdoor Play Environmental Categories

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Table 5. Nature-based ECE on UV Exposure								
Study details (Author, year and country) **Sample size** (n of children / n ECE settings for exp and con)	**Study Design**	**Outcome and measurement**	**Units**	**Baseline or one time point (cross-sectional)**	**Follow-up (if applicable) or mean difference**	**Summary of Findings**	**Effect Direction**	**Quality Rating**
Natural elements within ECE								
Boldemann et al (2004), Sweden. E: 64 children / 2 ECE	Cross-sectional	UV Exposure Measured using a Dosimeter (Biosense VioSpor blue line, type III 0.8–33 MED). Each child wore 2 Dosimeters attached to each shoulder using safety pins. They were worn during the school day.	UV exposure per day (JCIE/m^2)	Site 1: 222 JCIE/m^2, 15.3 % (95% CI 14.3–17.5, $p<0.05$) Site 2: 175 JCIE/m^2, 13.3 % (95% CI 9.9–14.6, $p<0.05$)		The was a statistically significant difference in UVR exposure between site 1 and site 2.	▲	Weak
Boldemann et al (2006), Sweden. E: 199 children / 11 ECE	Cross-sectional	UV Exposure Measured using a Polysulphone dosimeter (Diffey, 1984; Herlihy et al., 1994) The Dosimeter was pinned to the right shoulder and worn during school hours.	UV Exposure (J/m^2)	Low environment: ECE 3: 160 (95%CI:130–190) ECE 4: 241 (95%CI:200–281) ECE 6: 156 (95%CI:115–196) ECE 7: 83 (95%CI: 67–98) ECE 8: 269 (95%CI:214–324) ECE 10: 243 (95%CI:217–268)	Daily UV exposures ranged between 74 and 292 J/m	Outdoor environment quality was significantly associated with UV Exposure.	▲	Weak

				High environment: ECE 1: 104 (95%CI: 95–113) ECE 2: 129 (95%CI:104–154) ECE 5: 289 (95%CI:230–348) ECE 9: 292 (95%CI:232–351) ECE 11: 196 95%CI: 177–215)				
Christian et al (2019), Australia. E: 678 children / 48 ECE	Cross-sectional	UV Exposure Measured using a Polysulphone film mounted cardboard holders (UV badge) The UV badge was attached to the child's left shoulder and worn each day whilst at ECE for up to 3 days.	UV exposure (J/m^2) per average day of ECE.	% <3 m vegetation: β = -2.26 (95%CI -3.03, -1.49); p<0.01 % >3m vegetation: β = 0.91 (95%CI -12.46, 14.28), p= 0.89		ECE centre vegetation was significantly negatively associated with children's UVR exposure. For every 1% increase in centre vegetation, children's UVR exposure decreased by 2.3 J/m2 per day at ECE (p <0.01).	▲	Weak

Abbreviations: E= experimental; C= control; n= number; ECE = early childhood education (includes preschools, day care, kindergarten etc.); SD= standard deviation; SE= standard error; CI= confidence intervals.

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▲: positive association and statistical significance (p<0.05)
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Table 6. Nature-based ECE on harms								
Study details (Author, year and country) **Sample size** (n of children / n ECE settings for exp and con)	**Study Design**	**Outcome and measurement**	**Units**	**Baseline or one time point (cross-sectional)**	**Follow-up (if applicable) or mean difference**	**Summary of Findings**	**Effect Direction**	**Quality Rating**
Nature-based ECE								
Frenkel et al (2019), USA. E: 71 children / 5 ECE C: 70 children / 4 ECE	Controlled cross-sectional	Illness and injury Educators completed a standardised weekly illness and injury tracking log developed for this study. An illness episode was when a child was absent for at least 1 day due to illness (fever, respiratory, stomach, other).	Illness total Fever Respiratory Stomach Other	E: 1.49 C: 1.62 (age adjusted IRR: 0.93, 95% CI: 0.64, 1.34). E: 0.25 C: 0.47 E: 0.92 C: 1.01 E: 0.29 C: 0.37 E: 0.18 C: 0.07		No significant difference in the incidence of total illness between nature ECE and traditional ECE	▲	Weak
		An injury was counted if it required first-aid attention from teachers	Total injury	E: boys= 0.94 girls= 1.87 C: boys= 0.96 girls= 0.34		No significant difference in minor injury was found between boys at nature and traditional ECE. Girls at nature ECE had a significantly higher incidence of	▲ (boys) ▼ (girls)	

				boys: (age-adjusted IRR: 1.46, 95% CI: 0.59, 3.6) Girls: (age-adjusted IRR: 5.91, 95% CI: 1.98, 17.7).		minor injury compared with girls at traditional ECE.		
			Open wound/cut	E: boys= 0.60 girls= 1.31 C: boys= 0.48 girls= 0.23				
			Sprain	E: boys= 0 girls= 0 C: boys= 0 girls= 0				
			Child Bite	E: boys= 0.17 girls= 0 C: boys= 0 girls= 0				
			Other	E: boys= 0.17 girls= 0.56 C: boys= 0.48 girls= 0.11				

Moen et al (2007), Norway. E: 267 children / 37 ECE C: 264 children / 32 ECE	Controlled cross-sectional	Sickness absenteeism Parent noted daily reports of sickness absenteeism Absenteeism refers to the ratio of the total number of sickness absenteeism days to the sum of the number of sickness absenteeism days and the number of days the child was attending the day care centre during the study period.	Sickness absenteeism	estimate = - 0.0083, SE= 0.1830, t= 20.045, p> 0.05		No statistically significant difference in sickness absenteeism between the outdoor ECE and regular day ECE.	▼	Weak
Weisshaar et al (2006) E: 506 children / 25 ECE C: 1201 children / 28 ECE	Controlled cross-sectional	Tick bites and borreliosis Self- report questionnaire. Presence of at least 1 tick bite (yes/no). Presence of borreliosis (yes/no)	Tick bite % (presence – yes/no) Risk	Yes: E: 73.2% C: 26.6% No: E: 26.8% C: 73.4% p=0.0001 Adj OR= 6.74, 95% CI: 5.29–8.60		Children attending forest kindergartens reported a significantly higher prevalence of tick bites compared to the traditional kindergartens. Attending a forest kindergarten was a risk factor for having at least one tick bite when adjusting for age, sex, skin inspection and recommended vaccination.	▼	Weak
			Borreliosis % (presence – yes/no)	Yes: E: 2.0%		As above	▼	

				C:0.4% No: E: 98.0% C: 99.6% (p= 0.004)				
			Risk	Adj OR= 4.61, 95% CI: 1.50–14.17				
Natural elements within ECE								
Söderström at al (2013), Sweden. E: 172 children / 9 ECE	Cross-sectional	Symptoms (illness) The sum of days with symptoms of illness (runny nose, cough, fever, respiratory problems/asthma, itchy skin, diarrhoea, stomach ache, ear pain, body ache, sticky eyes, any medicine taken and days where parents had worries for their child). High score = less healthy.		p= 0.12 (descriptive statistics not presented)		Outdoor environment quality was not significantly associated with symptoms		Weak

Abbreviations: E= experimental; C= control; n= number; ECE = early childhood education (includes preschools, day care, kindergarten etc.); SD= standard deviation; SE= standard error; CI= confidence intervals.

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Qualitative

Table 7. Findings from eligible qualitative studies

Theme	Sub-theme	Studies	Quotes derived from participants or authors conclusions
Natural settings provide more affordances compared to traditional settings	Natural settings **enable** children to **diversify** their **play** (inc. risky, free and active play)	Dowdell et al (2011) Herrington & Studtmann (1998) Liu (2020) Puhakka et al (2019) Sandseter (2009) Wishart et al (2019)	*"You ask them what they are playing, they are going to tell you something different every day.", "we have some tree stems. they are in different sizes. they will line them up according size, they are smart kids. They line them up according to size and walk across, kind of like a balancing beam and they jump off them." (Liu, 2020).*
	Natural settings **enable** children to engage in **high intensity physical activity**	Bjørgen (2016) Puhakka et al (2019).	*"High physical-motor levels are created, the children jump down and run back up. They talk, shout and laugh. Three of the girls jump together and try to land in differing ways. They hold hands and try to jump together from the small knoll. There is laughter. They are eager and enduring. The small knoll has many opportunities for variation, in height and width, which invite challenges suitable for each child's resources. The children have visual, verbal and physical contact with each other. The top of the knoll provides an overview. Some find it scary the first time they try, but together they challenge each other, supporting and encouraging each other. The children decide how much they will participate and how they jump, and how they wish to solve the challenges offered by the knoll" (Bjørgen, 2016).*

	Natural settings **afford** children with **higher levels of risk** compared to traditional settings	Sandseter (2009) Streelasky (2019)	*I like playing in the fallen logs and trees on the playground; it is so much fun, but a bit scary too! I like the big pile of sticks and logs that we made – it is for another fort that is going to be really high off the ground." (Streelasky, 2019)*
	Natural settings **enable peers and teachers to interact differently**	Bjørgen (2016) Dowdell et al (2011) Liu (2020) Streelasky (2019).	*"The children are shouting 'X… can't you catch us? Please catch us, try to catch us …'. The staffs join the situation and run after the children. The children are shouting 'Catch me … can't catch me' … There is excitement and the staff are running after the children, catching them and holding them before releasing them. The staffs have high energy, the children focus on the adults, avoiding being caught. The adults show empathy, holding and hugging the child when it is caught. The game is exciting and creates enthusiasm. A high level of physical activity is created, by climbing up, sliding down, running around and hiding in the tower to escape capture by the adults. They run at high speed and the children's body language shows that they are very much engaged in the game" (Bjørgen, 2016)* "*I try to do different things with them every day. Like I said, we play with them at least then minutes. So, I try to run, parachute, the blocks, climbing, sliding down the slides." (Liu, 2020).*
Natural and traditional settings provide similar affordances	**Movement types and intensity** similar across natural and traditional playgrounds	Wishart et al (2019).	Not available.
	Opportunity for and frequency of risky play is similar in both natural and traditional settings	Sandseter (2009)	*"Comparing the two play environments, they both seem to include an extensive amount of affordances for risky play. At both preschool playgrounds, there are opportunities for play in great heights such as climbing, jumping down, and balancing and as well as opportunities for play with high speed such as swinging, sliding/sledding, running, and bicycling."* Taken from authors conclusions – (Sandseter, 2009)

Natural environment is more diverse and engaging, and preferred by children for play compared to traditional settings		Bjørgen (2016) Streelasky (2019)	*"I like going outside and playing! I like playing with my friends, Sydney and Megan. We play hide and seek on the playground and hide in the forest in the logs and trees. I like outside because it's so fun and I really like to play. Sometimes I play with my sister too; I like all the colours outside and all the space." (Streelasky, 2019).*
Restorative and invigorating effect of nature		Puhakka et al (2019),	*"Now it's become very difficult to finish playing. They would rather continue, and those who need to take a nap, they've had a nice, long time outdoors and nice games so they fall asleep more easily, and it affects their energy in the afternoon. Some children have very long days here. They come in the morning and stay until five o'clock; they seem to be somehow energetic and lively in the yard. This is new for us. The contrast to the previous yard is so great that the effects can be seen here very quickly." (Puhakka et al, 2019).*

Additional file 6. Synthesis of qualitative and quantitative findings

Themes from qualitative studies	**Quantitative results**		
	Nature-based ECE	**ECE Natural playgrounds**	**Natural elements within ECE**
Natural settings enable children to **diversify their play**	Children engaged in a range of physical activity types; Better balance and locomotor skills (running, skipping, hopping), strength and jumping.	-	-
	Lower speed and agility	-	-

Natural settings enable children to engage in **high intensity physical activity**	Conflicting findings in MVPA doesn't suggest higher PA intensity	Decrease or no improvement in MVPA	Decreased MVPA as number of hilly landscapes, natural surfaces and vegetation increased.
Natural settings afford children with **higher levels of risk** compared to traditional settings	More minor injuries	-	-
Movement intensity similar across natural and traditional spaces	Conflicting findings in MVPA doesn't suggest similarity between spaces	-	No difference in MVPA
Movement types similar across natural and traditional spaces	No evidence of different object control skills and total motor competence which comprised of manual dexterity, ball skills and balance and total fitness scores	-	-
Restorative and invigorating effect of nature (playground)	Lower daytime sleepiness	-	Better sleep outcomes

Abbreviations: ECE = early childhood education; MVPA = moderate-to-vigorous physical activity; PA = physical activity

Green = confirmatory (i.e. quantitative results confirm qualitative themes); orange = conflicting (i.e. quantitative results conflict qualitative themes).