ENHANCING EXECUTIVE FUNCTIONS IN EARLY CHILDHOOD: A SYSTEMATIC REVIEW OF INTERVENTIONS IN PRESCHOOL SETTINGS

POTENZIARE LE FUNZIONI ESECUTIVE NELL'INFANZIA: UNA REVISIONE SISTEMATICA DEGLI INTERVENTI IN CONTESTI SCOLASTICI

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ABSTRACT
In recent years, the scientific community has increasingly emphasized the importance of executive functions (EFs) in early childhood development. Yet, educational strategies to enhance EFs in preschool, especially in low-SES contexts, remain underexplored. This systematic review investigates the relationship between learning environments and the development of EFs in preschoolers, aiming to identify school-based interventions that support equitable development and learning for all children.

Negli ultimi anni, la comunità scientifica ha sottolineato l'importanza delle funzioni esecutive (FE) nello sviluppo dell'infanzia. Tuttavia, le strategie educative per potenziare le FE, soprattutto in contesti di svantaggio, restano poco esplorate. Questa revisione sistematica indaga la relazione tra ambienti di apprendimento e sviluppo delle FE nei bambini in età prescolare, con l'obiettivo di individuare interventi scolastici capaci di sostenere uno sviluppo e un apprendimento equi per ciascuno.

KEYWORDS
Early Childhood Education, learning environments, executive functions, school-based interventions

Educazione infantile, ambienti di apprendimento, funzioni esecutive, interventi scolastici

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Introduction

In recent years, the scientific literature has increasingly emphasized the crucial role of early childhood learning environments (ECLE) in promoting holistic development. In fact, early life, environmental experiences shape neurological, cognitive, emotional and social growth. The educational context, seen as a network of relationships, practices, and daily stimuli (Malaguzzi, 2010), acts as a space of care and learning that can support or hinder development, particularly in the presence of vulnerabilities such as disability or socioeconomic disadvantage (Berti et al., 2019).

Among the key developmental domains supported by high-quality ECLE, executive functions (EFs) have received growing attention for their foundational role in learning and social participation. Due to their multifactorial nature, inclusive, emotionally supportive, and intentionally structured ECLE are essential (Methlagl et al., 2024), acting as both protective buffers and facilitators of cognitive and self-regulatory capacities (Sankalaite et al., 2021).

EFs include top-down cognitive processes such as working memory, inhibition, and cognitive flexibility, which emerge rapidly in early childhood and underlie planning, reasoning, and problem-solving (Miyake et al., 2000). A common distinction is drawn between “cool” EFs, activated in emotionally neutral contexts and linked to the dorsolateral prefrontal cortex, and “hot” EFs, engaged in emotionally salient situations and associated with the orbitofrontal and limbic systems (Leshem et al., 2020; Londono et al., 2024).

Their development is highly sensitive to environmental quality, especially during early childhood when brain plasticity is at its peak. ECLE offering play, movement, emotional interaction, and structured routines are shown to enhance EF development (Diamond, 2012; Diamond & Ling, 2016), with embodied practices such as music and play yielding additional benefits (Diamond, 2013).

This is especially urgent for children from low socioeconomic status (SES) backgrounds or with disabilities, who are at increased risk for EF difficulties (Blakey et al., 2020). Poverty-related adversity—affecting caregiving, emotional stimulation, nutrition, sleep, and language—impacts brain areas related to EF such as the prefrontal cortex and hippocampus (Mills-Koonce et al., 2022). Stress models suggest that early exposure to unpredictable environments may accelerate emotional maturation (Rakesh et al., 2023), while chronic poverty is linked to slower development and reduced cortical growth (Hamza et al., 2024).

Beyond biology, poverty also acts through ecological and psychosocial pathways. Disadvantaged children often show underdeveloped non-cognitive skills—such as self-regulation, motivation, creativity, and relational abilities—that may predict academic failure and marginalization (Folci, 2024; Munoz-Chereau et al., 2021; Schmidt et al., 2021). Theories such as Bronfenbrenner's ecological model (1979) and the bio-psycho-social perspective underscore how development results from biological, psychological and social interaction.

Within this framework, school is a critical microsystem with the potential to counteract disadvantage and promote inclusion through accessible and supportive environments. Drawing on embodied cognition (Gomez Paloma, 2004), these spaces should value the role of the body in learning through movement, sensory experience, and physical interaction. Investing in ECLE quality means promoting embodied and inclusive practices that advance developmental equity and children's long-term well-being.

Currently there is a significant lack of studies documenting school-based interventions that are deliberate and aligned with scientific evidence on children's developmental needs, interventions that could guide pedagogical decision-making in a targeted and evidence-based manner. Therefore, the current systematic review explores how ECLE support the development of EFs, aiming to identify educational practices and school-based interventions

In particular, the research questions that guided the review process are:

RQ1: What is known about the relationship between ECLE and the development of EFs, in terms of school-based interventions?

RQ2: In particular, what is known about the RQ1 in preschool children from low-SES backgrounds?

1. Methods

A systematic review was carried out to identify studies that investigate the relationship between ECLE and the development of EFs in preschool children. The review was conducted according to the PRISMA guidelines (Page et al., 2021). The study protocol was registered with the International Prospective Register of Systematic Reviews (No. CRD420251030809).

1.1 Eligibility criteria

To ensure the relevance and methodological rigor of the included studies, specific eligibility criteria were defined a priori based on the PICOS framework (Higgins et al., 2024). To be included in the review, studies had to meet the following criteria: 1) target population aged 3-5, enrolled in preschool or early childhood education settings; 2) include interventions or practices implemented within educational environments; 3) report at least one outcome related to executive functions; 4) be published between 2020 and 2025; 5) be written in English. Studies were excluded if they a) focused exclusively on clinical or home-based interventions; b) presented a correlation of data to predict learning or developmental outcomes without any intervention; c) included participants outside the preschool age range; d) were classified as grey literature (e.g., thesis, reports, conference papers).
The authors chose not to restrict the inclusion of studies based on design type, allowing for both randomized and non-randomized studies. Additionally, studies were included if they initially involved participants aged 3–5 years, even when follow-up data extended beyond this age range. This decision aimed to capture longer-term outcomes of early interventions.

1.2 Search strategy

A literature search, completed in April 2025, was carried out using the following electronic databases: Scopus, EBSCO, Web of Science, PubMed, Google Scholar. Relevant keywords and Boolean operators were used to ensure precision and inclusiveness. The main search terms included combinations of: "learning environment*" OR "educational space*" AND "preschool*" OR "early childhood education" OR "ECE" OR "early intervention" AND "executive functions" AND "low income level" OR "low SES".
Search strategies were adapted for each database.

1.3 Selection process

The studies selection process followed the PRISMA 2020 guidelines (Figure 1). After removing the duplicates, all titles and abstracts were independently screened by two authors. Full texts of potentially eligible studies were then retrieved and

evaluated based on the predefined inclusion and exclusion criteria. Disagreements were resolved through consultation with the third author.

In detail:

1) The literature search conducted across the selected databases using the keywords listed above initially yielded **736 records**;
2) After removing duplicates, **723 records** remained;
3) A title and abstract screening was independently performed by two authors, resulting in the selection of **81 potentially relevant studies**;
4) Following full text review and application of the eligibility criteria, **17 studies** were finally included in the systematic review.

The screening described in point 3 was carried out using the Rayyan software (Ouzzani et al., 2016).

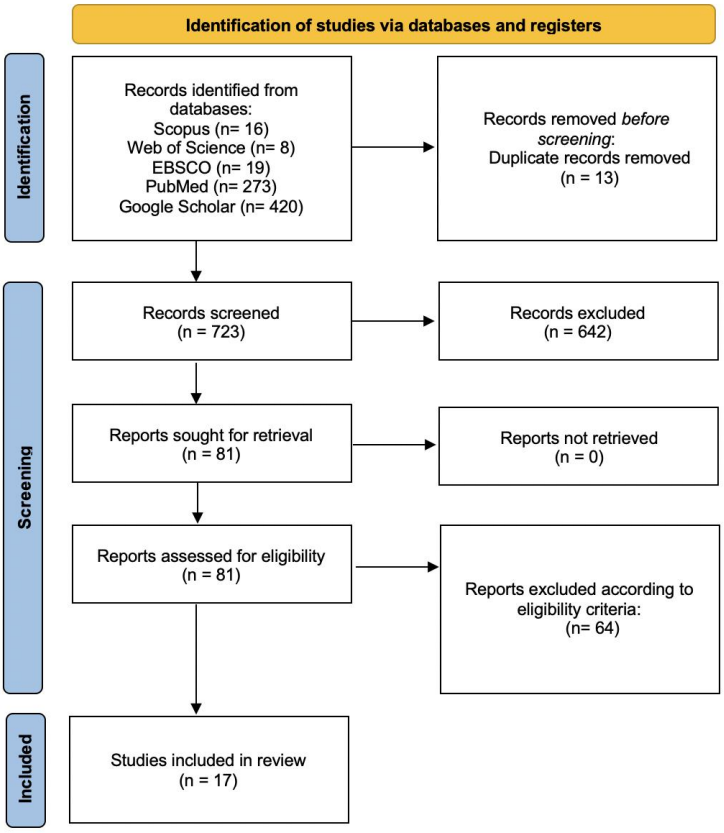

Figure 1. Flow diagram of the literature screening process (Page et al., 2021).

1.4 Data collection process

Relevant data were extracted independently by two authors from the included studies and coded using MAXQDA24 software. No automation tools were used in the process. Before starting the extraction process, the authors agreed on a predefined set of variables to be collected in order to ensure consistency across reviewers. The extracted information include: 1) authors, year of publication, country; 2) study design; 3) sample characteristics (number of children, age, SES, disability); 4) type and duration of intervention, presence or absence of a control group; 5) measurement tools; 6) learning environment features; 7) targeted executive functions; 8) main findings. Any discrepancies were resolved through consultation with a third reviewer.

1.5 Study risk of bias assessment

The risk of bias was assessed using the Cochrane RoB-2 (Sterne et al., 2019) tool for randomized controlled trials and the ROBINS-I (Sterne et al., 2016) tool for non-randomized studies. Two critical confounding variables were defined a priori: 1) child age; 2) the actual implementation of an intervention within the preschool environment. Studies that failed to provide clear documentation on the age distribution of participants or lacked explicit evidence of an implemented intervention were rated as having a higher risk of bias in the confounding domain. All assessments were conducted independently by two reviewers, and disagreements were resolved through consensus or consultation with the third reviewer when necessary.

2. Results

The analysis of the 17 included studies revealed a diverse range of interventions, methodologies and outcomes related to EFs development in ECLE. The overview of the studies analyzed is shown in Table 1.

Table 1. Included studies.

References / countries	Study design	Sample	Type and duration of intervention / control group	Measurement tools	Learning environment features	Targeted EF	Main findings
An Kim, 2025 *USA*	Longitudinal quantitative study	18.170 preschool children (310 identified as having ASD)	Investigate whether attending pre-kindergarten predicts better working memory development in all children and whether pre-K education is particularly beneficial for autistic children's working memory development, controlling for SES / 1 year; WM tracked from kindergarten to fifth grade / control group	WJ III – Woodcock-Johnson III (Woodcock et al., 2001); parent interviews	Pre-K programs	Working memory (WM)	Children that received **pre-K education** the year before kindergarten predicted advanced **working memory** at fall of kindergarten and spring of first grade. Children with ASD show pre-K education's positive predictive power later (spring of first grade) and the effects last longer (until spring of third grade). Pre-k learning environment can reinforce behaviors related to **advanced approach to learning** and **positive STI** (linked to advanced WM for children with ASD). Socioeconomic status significantly predicted working memory at all time points, confirming that children from **low SES backgrounds had lower WM scores** overall. While SES was statistically controlled, the findings highlight the need to expand access to high-quality pre-K programs, particularly for **autistic children from disadvantaged backgrounds**, to reduce inequities and support long-term cognitive development
Cheng et al., 2025 *USA*	Longitudinal quantitative study within a larger randomized-controlled trial	267 children (39-54 months) from low SES backgrounds (30% had an IEP) and 97 educators	Examine whether different aspects of classroom quality (emotional support, organization, instructional support) predicted changes in preschool learning behaviors (PLBs) among children at developmental and socioeconomic risk / 2 years / control group	CLASS – Classroom Assessment Scoring System-PreK (Pianta et al., 2008); PLBS – Preschool Learning Behaviours Scale (McDermott et al., 2002)	Low-income preschool classrooms	Attention and persistence; motivational behaviors related to self-regulation	Higher classroom **emotional support** significantly predicted increased Preschool Learning Behaviors (PLBs), with a standardized regression coefficient **β = .307**, p = .020, and a small-to-medium effect size. Similarly, **classroom organization** predicted higher PLBs (**β = .287**, p = .008). These learning behaviors included **competence motivation**, **attention/persistence**, and **attitudes toward learning**. The variance explained for each subscale was substantial: **90.2%** for competence motivation, **75.8%** for attention/persistence, **18.3%** for attitudes toward learning (in the emotional support model). In contrast, **instructional support** did not significantly predict PLBs (p> .05). The results underscore the critical role of emotionally supportive and well-organized classroom environments in fostering executive-function-related learning behaviors in children facing both **socioeconomic disadvantage and developmental vulnerabilities**
Etokabeka, 2024 *South Africa*	Qualitative multiple case study design	8 preschool teachers and children aged 3-6 years observed	Explore different teaching techniques to support EF behaviour during structured play / 8 observations lasting	Semi-structured interviews and classroom observations	Preschools that follow Montessori, Reggio Emilia, Independent School	WM; self-regulation; planning; organizing; attention	Teachers supported the development of executive functions through six main techniques: **guiding, modelling, instructing, repeating, incorporating child-led activities, and considering**

			3-5 hrs / no control group		Association of South Africa, and National Curriculum Framework		**children's interests**. Structured play activities such as puzzles, LEGo building, finger painting, obstacle courses, memory games and songs were used to foster skills like attention, self-regulation and WM.
Kellens et al., 2023 *Belgium*	Quasi-experimental pilot study	224 children (3.9 to 6.8 years old) and 24 teachers from 8 preschools (46.9% children from low SES backgrounds)	Evaluate the effectiveness of the classroom program "Put your EF glasses on", aiming to improve EF in preschoolers, particularly those from low-SES backgrounds, by enhancing teacher-child interactions, implementing EF-supportive activities, and improving classroom organization / 5 months programme from pretest and posttest / control group	BRIEF-P – Behavior Inventory of Executive Functioning – Preschool version (Gioia et al., 2000)	Preschools with at least 30% low SES enrollment; intervention within the natural classroom context	WM; shifting; inhibition; planning; organizing; emotional control	Three building blocks training for experimental groups (both full and light): **high-quality teacher-child interaction**, **EF-supporting activities**, **supportive classroom structure**. Significant interaction between **Global executive composite** and SES status: significant intervention effect for low-SES children; significant interaction effect on low SES children's **WM**; the program significantly impacted **shifting** problem scores only in low SES children; after excluding 3 outliers, low-SES children showed significantly weaker **inhibition** and higher posttest problem scores compared to their middle-to-high-SES peers, even after controlling for pretest levels; low-SES children in the intervention group showed significantly improved **planning and organizing skills** at posttest—evidenced by lower problem scores—after controlling for pretest levels, indicating a beneficial interaction between SES and program participation; no significant interaction effect on **emotional control**
Keown et al., 2020 *New Zealand*	Cluster randomized controlled trial	212 4-year-old children (age from 47 to 58 months)	Evaluate the effectiveness of a classroom-based intervention "Red Light Purple Light (RLPL)" to enhance children's EF skills / 8 weeks of twice weekly 20 to 30 minutes sessions of the intervention / control group	HTKS – Head-Toes-Knees-Shoulder (Cameron Ponitz et al., 2009); DCCS – Dimensional Change Card Sort (Frye et al., 1995); CBRS – Child Behavior Rating Scale (Bronson et al., 1990); BPVS-3 - British Picture Vocabulary Scale: Third Edition (Dunn & Dunn, 2009); teacher interviews	15 ECE bound by the national curricular framework *Te Whāriki* (bicultural framing) (low SES= 7; mid-SES= 8)	Cognitive flexibility (shifting); WM; inhibitory control (IC);, behavioral self-regulation	Children from the intervention group show significant intervention effect on **EF skills** at post-intervention (**DCCS** task: IG – T1: 10.60/ T2: 21.00 vs CG – T1: 14.80/ T2: 16.70); no statistically significant intervention effect at post-intervention for **HTKS** (IG – T1: 13.80/ T2: 25.20 vs CG – T1: 14.80/ T2: 23.70) and **CBRS** (IG – T1: 33.50/ T2: 37.60 vs CG – T1: 34.80/ T2: 36.10); higher scores on **CBRS** at 4-month follow up for intervention group (IG – T3: 39.70 vs CG – T3: 36.60); teacher interviews indicated additional perceived benefits in children's listening, social skills, and leadership. Although the study included centers from low-SES areas, it did not report differential outcomes by **SES**
Liu et al., 2022 *China*	Randomized controlled trial	48 normally healthy and developing children (aged 4-5 years)	Assess the effects of exergames intervention training on preschool children's EF / four-week intervention with daily 30-minute sessions / control group	EYT – Early Years Toolbox (Howard & Melhuish, 2017): Go/No-Go task, Card Sorting task, Mr. Ant	Kindergarten classroom; exergame setup include Nintendo Switch consoles	IC; cognitive flexibility (shifting); visual-spatial WM	At **baseline**, there was no statistically significant difference in measurement scores between IG and CG; significant intervention effects on **inhibition** after 4 weeks (between T0 and T2 – IG: 0.123 vs CG: 0.005 = IG was on average 0.118 larger than CG);

					and "Just Dance" software		significant intervention effects on **shifting** after 2 weeks (IG increased on average 1.292 points more than CG) and 4 weeks (IG increased on average 1.125 points more than CG); significant intervention effects on **WM** after 4 weeks (between T0 and T2 – IG: 0.819 vs CG: 0.222 = IG was on average 0.118 larger than CG)
Lu et al., 2025 *USA, Germany, China, UK, Canada*	Systematic review and meta-analysis of 12 studies (10 included in the meta-analysis)	807 healthy children aged 3-6 years (some included participants from low-income families)	Evaluate the effects of music training on EFs / ≥12 weeks; session lengths ranges from 20 to > 40 minutes; frequency ranged from 1 to 5 times/week / control group	NEPSY-II; Peg Tapping; Baby Stroop; Spin the Pots; DCCS; Trucks; Day/Night Stroop Task; Go/No Go; Mr. Ant; Card Sorting; Matrix Span Test; Corsi Block Test; Word Span; Pictorial Memory; Backward-Digit Span Task	Preschool settings involving group-based music activities integrated into the curriculum	IC; WM; cognitive flexibility	Longer music-intervention periods (≥12 weeks) are more beneficial for improving **inhibition**; music training improve **inhibition** in children from low SES families; enhancements in **verbal** and **visuomotor inhibition** in high-income families; moderate positive effect on preschoolers' **WM**, especially with programs lasting 12 weeks or more and sessions of 20–30 minutes; small but positive effect on improving **cognitive flexibility** in preschoolers, especially when delivered frequently, for longer durations (≥12 weeks), and in sessions of ≥40 minutes. Short-term interventions may be less effective due to task complexity and the later developmental trajectory of cognitive flexibility
Rege et al., 2024 *Norway*	Field experiment (cluster randomized controlled trial)	691 5-years-old children (the study assessed par ental education, income and immigrant background to examine heterogenei ty)	Introduce a structured curriculum and evaluate the impact on children's development in mathematics, language, social skills and executive functioning / 9 months with 8 hrs/week structured activities / control group	Ani Banani Math Test for assessing mathematics skills (Størksen et al., 2018); Norwegian Vocabulary Test and Phonological Awareness Test for assessing language skills; Digit Span Test (Wechsler, 1991); Head-Toes-Knees-Shoulders task (McClelland et al., 2014); Hearts and Flowers test (Davidson et al., 2006)	Structured skills-based curriculum within 71 preschools (130 learning activities about math, language, executive functions, social competenc es), teacher training	WM; IC; cognitive flexibility	Treatment effect in **mathematics** is larger in T3 as compared to T2: 15.5 percent of a standard deviation in T2 (not significant) and 22.8 percent in T3 ($p<0.01$); immediate positive treatment effect on **executive functioning** of 14.6 percent of a standard deviation ($p<0.05$), but the effect fades by the follow-up assessment; no effects on **language**; treatment was especially effective in preschools initially classified as low-quality. One year after the intervention, these centers showed a 22% standard deviation improvement in overall child outcomes—19% greater than in high-quality centers. Notably, children in **low-quality centers** demonstrated significant gains in both mathematics (31.1%, $p<0.01$) and language (15.7%, $p<0.05$); no significant impact on executive functioning. No differential effects were found based on **parental education** or **baseline skill levels**, suggesting that all children, regardless of SES, benefited equally from the curriculum
Ruffini et al., 2021 *Italy*	Pilot quasi-experimental study	18 typical developing 4-5 years old children	Test the feasibility and efficacy of the Italian version of *Quincey Quokka's Quest* (QQQIT), a	Simon Says (Marshall & Drew, 2014); Day-Night Stroop, Keep	Session in dedicated quiet kindergart	IC; verbal and visuospatia l WM; cognitive	Significant gains in **cognitive flexibility**, as shown by improved performance in the Color and Form Game (overall accuracy

			dialogic reading intervention designed to enhance EFs in preschoolers through structured playful storytelling / 8 weeks with 1 weekly session lasting 20 minutes / no control group	Truck, Color and Form Game (Usai et al., 2017); Mr. Ant (Morra, 1994); BRIEF-P (Gioia et al., 2014)	en classroom	flexibility (shifting)	increased from M=15.5 to M=18.39, p <0.05), particularly in the Form and Border conditions (Cohen's d = 0.91 and 1.65, respectively). Gains were also noted in **visuospatial WM** (Mr. Ant task, M=2.15 to 2.68, p < 0.05), though with a small effect size (d = 0.25); no significant post-intervention effects in: **Inhibition** and **Verbal WM.** Positive trend during the training: all QQQIT activities showed a **systematic performance improvement** from the first to the last session, in particular, significant progress was observed in activities requiring **inhibition, shifting,** and **interference control**
Størksen et al., 2023 *Norway*	Cluster randomized controlled trial	1.313 5-years-old children (26% children from low-SES backgrounds)	Examine the effects of the Playful Learning Curriculum in ECEC on children's school readiness skills, with a focus on mathematics, language and EFs / 9 months with 8hrs/week / control group	ABMT – Ani Banani Math Test (Braak & Størksen, 2021); PENS – Preschool Early Numeracy Skills Screener (Purpura & Lonigan, 2015); NVT – Norwegian Vocabulary Test (Størksen et al., 2013); Weschler's Intelligence Digit Span Test (DS)	96 play-based ECEC context	WM	Significant gains in **mathematics**, with small but statistically meaningful effects on ABMT (d = .079, p = .03) and PENS (d = .104, p = .01). However, no significant effects were found on **WM** (d = .070, p = .14) or vocabulary (d= –.011, p = .65). Analyses found no differential effects for children from **low SES families** or for those with lower pre-test scores, meaning the intervention benefited children regardless of socioeconomic background, but **did not produce extra gains** for more vulnerable groups
Sun et al., 2020 *Singapore*	Correlational longitudinal study	173 children (mean age 4 years and 9 months) and 20 teachers (low-SES children included with variation in maternal education and household income)	Investigate whether teachers' code-switching (CS) behavior—both intra-sentential and inter-sentential—affects bilingual preschool children's language output, heritage language (HL) vocabulary, and cognitive flexibility / 1 year / no control group	BLAB - Bilingual Language Assessment Battery (Rickard-Liow & Sze, 2009); DCCS - Dimensional Change Card Sort (Slotkin et al., 2012); Raven's Colored Progressive Matrices (Raven, 1947)	20 bilingual preschool classrooms	Cognitive flexibility	Teachers' use of code-switching, particularly intra-sentential code-switching, was positively and significantly associated with children's own use of intra-sentential code-switching in the classroom. Regarding **vocabulary development**, neither intra-sentential nor inter-sentential code-switching by teachers significantly predicted children's HL vocabulary growth. Interestingly, the study found a significant positive relationship between teachers' intra-sentential code-switching and children's development in **cognitive flexibility** (DCCS score from K1 to K2, p = .03). This suggests that exposure to mixed-language input in naturalistic classroom settings may support the development of **non-verbal executive functions**, even in the absence of targeted vocabulary gains
Tandom et al., 2020 *USA*	Longitudinal quantitative cohort study	495 children aged 3 to 5 years (average 4.2 years) from 72 classrooms within 1335 ECEC (35% children	Examine the quality of gross motor and physical activity environments in preschool settings and to analyze how these are associated with early learning outcomes,	ECERS-R - Early Childhood Environment Rating Scale (Gordon et al., 2013); WJ III - Woodcock-Johnson III Tests of Achievement	Physical activity environment	Self-regulation	Daily access to **gross motor equipment** and the structured inclusion of both **indoor and outdoor play periods** are strongly associated with improved self-regulation skills, as indicated by higher scores on the HTKS (β = 5.20; β = 7.32). Additionally, the **variety of daily play activities** and the

		from low-SES backgrounds)	including executive functions / fall to spring within one academic year / no control group	(Woodcock et al., 2001); LENS – Lens on Science (Greenfield & Penfield, 2009); EWA – Early Writing Assessment (Puranik et al., 2011); HTKS – Head Toes Knees and Shoulders (McClelland et al., 2014); TEAM – Tools for Early Assessment in Math (Clements & Sarama, 2011); PPVT-4 – Peabody Picture Vocabulary Test (Dunn & Dunn, 2007); CBCL – Child Behavior Checklist (Achenbach & Ruffle, 2000)			**substantial time devoted to play** show positive associations with emerging scientific competencies, as measured by the Lens on Science (β = 0.57), and with behavioral self-regulation (CBCL β = 4.79). From a behavioral standpoint, the presence of **gross motor equipment** are significantly associated with reduced behavioral problems, as assessed by the CBCL (β = –3.47; β = –4.52). However, a negative association was observed between **staff-child conversations** about play and **receptive vocabulary development** (PPVT β = –2.87), suggesting that the quality of verbal interactions during unstructured play may need closer examination. Finally, it is worth noting the absence of data regarding **adaptations for children with disabilities**, highlighting a critical gap in assessing the inclusivity of early learning environments and pointing to the need for future research specifically addressing accessibility and participation for all children
Ureña et al., 2020 *Spain*	Randomized controlled trial	49 preschool children aged 4-5 years (1 ADHD child; 1 immigrant)	Examine whether classroom movement breaks (CMBs) involving different levels of cognitive challenge during physical activity could lead to immediate improvements in self-regulation, as a behavioral proxy for executive functions / one-shot intervention (20 minutes) / control group	HTKS – Head Toes Knees and Shoulders (Benzing et al., 2016)	Preschool classrooms	WM; inhibitory control; cognitive flexibility	All three experimental groups (Bike Locomotion – BL, Without Bike Locomotion – WBL, and Dramatic Story – DS) showed significant improvements compared to their pre-test performance, whereas the control group showed no change. The walking locomotion (WBL) and bike locomotion (BL) groups improved significantly more than the control group in overall **HTKS scores** ($p < 0.001$), especially in Part 2, which tested task-switching and dual-rule execution (BL: $d = 1.204$; WBL: $d = 1.422$). Additionally, these groups showed significant gains in **Cognitive Control Estimation** scores ($p < 0.001$), suggesting a shift toward proactive control mechanisms. However, only the WBL group showed improvement in task change, likely because the BL group's increased cognitive and physical demands may have caused fatigue, limiting benefits
Vazou and Mavilidi, 2021 *USA*	Cluster randomized controlled trial	273 preschool children aged 3-5 years (49-75% of participants were from low parental income)	Evaluate the feasibility, usability and effectiveness of the "Move for Thought (M4T) preK-K" program a curriculum integrating cognitively engaging physical activity with academic content and social-emotional learning—to improve executive	SWAN – Strength and Weaknesses of ADHD symptoms and normal behavior questionnaire (Swanson et al., 2012); SSRS – Social Skills Rating Scale questionnaire (Gresham &	16 preschool classrooms	Hot and cool executive function	Significant improvement in **attention** in the children in the intervention group compared to the control group, indicating a positive effect of integrating cognitively engaging motor activities into the school routine. There were no significant differences between the groups with regard to **cold EFs** (measured with the Day-Night task) and **hot EFs** (cooperation, assertiveness, and self-control measured with

			functions, attention, behavioral control, social skills, and perceived motor competence / 8 weeks with one 10-minutes session/day / control group	Elliot, 1990); Day-Night Stroop (Gerstadt et al., 1994); PMSC – Pictorial scale for Perceived Movement Skill Competence (Barnett et al., 2016)			the SSRS scale), although both groups showed improvement over time, possibly due to maturation or learning effects. In addition, the perception of motor competence did not change significantly, probably due to a plafon effect due to the age of the children and the self-reported nature of the measure. Data collected from teachers' daily diaries confirmed high fidelity to implementation and a high level of physical and cognitive engagement during activities. The study shows that the program is realistic to implement in preschool school settings and may have positive effects on attention, but more consistent results on executive and social-emotional functions may require a longer duration of intervention and greater support for teachers
Vidal Carulla et al., 2021 *Sweden*	Longitudinal qualitative study using ethnography approach	20 preschool children aged 3-4 years	Explore the development of executive functions through a play-based learning intervention focused on science activities / 15 months / no control group	Video-recorded classroom observations with indicators for WM, inhibitory control and attention shifting inferred from body language and verbal cues	Play-based learning environment	Cognitive flexibility; IC; WM	Children progressively developed their executive functions, particularly **inhibitory control** (IC) and **attention shifting** (AS). Initially, their behaviors were primarily egocentric, focusing on their own preferences and actions. Over time, they began to acknowledge others' perspectives, first through imaginary characters in the narrative context and later by recognizing the preferences and viewpoints of their peers. **Verbal** and **social interactions** became more collaborative, and children started to co-create alternative storylines during activities. Although these new narratives sometimes deviated from the planned scientific tasks, they represented meaningful instances of **cognitive flexibility** and **social regulation**. The activities thus served as a bridge for transferring executive function skills from fictional play to real-life situations, demonstrating that science-based, play-centered learning environments can effectively support the development of preschoolers' executive functions
Violant-Holz et al., 2023 *Spain*	Mixed methods combining qualitative (photography-based observation) and quantitative (data mining with CHAID classification tree)	16 preschool teachers and 328 children aged 3 to 6 years	Identify and classify the pedagogical action patterns that preschool teachers use to promote healthy habits (nutrition, hygiene, physical activity, and emotional health), and to explore how these actions relate to EFs development, using photography	ESAR model – Exercise, Symbolic, Assembly, Rules (Garon, 1992)	Naturalistic preschool setting	Self-regulation; WM; cognitive control (functional ability); flexibility and planning (symbolic activity)	**School spaces** (especially playgrounds and psychomotricity rooms) and the **learning strategies** defined by the ESAR model were the strongest predictors of teachers' pedagogical actions promoting healthy habits. Actions related to physical activity were mostly observed in outdoor or movement-specific areas, while emotional health and hygiene were more addressed in classrooms. The development of **EFs** was

			and CHAID decision-tree analysis / 2 photo-based observations sessions in 4 months / no control group				implicitly supported through strategies like social interaction, affective expression and language use. Emotional health emerged as the most frequently targeted health dimension, suggesting a prioritization of mental-being in early childhood education. Classroom routines are important for the development of executive functions because they provide a structured and predictable environment where children can practice skills such as self-regulation, inhibitory control, working memory, and cognitive flexibility
Xu et al., 2024 *USA, China, Italy, Portugal, South Korea, Australia, Belgium, Canada, Chile, Ecuador, Ghana, Lithuania, Romania, Mexico, Netherlands, Turkey, UK, United Arab Emirates*	Three-level cross-cultural meta-analysis of 84 quantitative empirical studies (32 cross-sectional, 52 longitudinal)	68.296 children (mean age: 64.83 months= 5.4 years) (children with disabilities included in a small portion of studies; 35.71% of children from low-SES backgrounds)	Examine the relationship between teacher–student interaction (TSI)—including dyadic (closeness, conflict, dependency) and classroom-level (emotional support, classroom management, instructional support) dimensions—and EFs development in children / both control and no control group	(See *Supplementary Files* in the original paper)	18 cultural regions, including preschools and primary schools	Hot and cool EFs	All dimensions of positive teacher–student interaction were significantly associated with better EF in children. The strongest correlations were found for **dyadic TSI** (r=.251), **closeness** (r=.184), and **conflict** (r=−.262). Classroom-level TSI had smaller effect sizes: **emotional support** (r=.086), **classroom management** (r=.135), and **instructional support** (r=.079). These associations were **stronger when EF was measured via adult reports** compared to direct assessments. Regarding SES, **emotional support** and **classroom management** had **stronger positive effects on EF in medium-to-high SES children**, with effect sizes of *r=.139–.233*, compared to lower SES children, who showed smaller gains (*r=−.012 to .090*). This suggests that **higher SES children benefited more** from positive teacher–student relationships in terms of EF development. Cultural moderators (e.g., power distance, individualism) also influenced outcomes

2.1 Study characteristics

The studies were carried out in USA (n= 6); New Zealand (n= 1); South Africa (n= 1); Belgium (n= 2); China (n= 3); Germany (n= 1); UK (n= 2); Canada (n= 2); Norway (n= 2); Italy (n= 2); Singapore (n= 1); Spain (n= 2); Sweden (n= 1). One multi-country study (Xu et al., 2024) also included Portugal, South Korea, Australia, Chile, Ecuador, Ghana, Lithuania, Romania, Mexico, Netherlands, Turkey, United Arab Emirates.

2.2 Population

The studies involved children primarily in preschool settings, with participant ages ranging from 3 to 5 years. While most studies focused on typically developing children, several included subgroups with specific characteristics. Four studies explicitly included children with disabilities or developmental risks (e.g., autism, ADHD or IEPs), while nine studies involved children from low SES backgrounds, either partially or as the main target group. A few studies did not report detailed demographic characteristics and are therefore assumed to involve typically developing children from mixed backgrounds. Additionally, some studies reported follow-up data extending beyond the preschool years, although the initial sample fell within the 3-5 range.

2.3 Study design

The review included a variety of study designs to capture the diversity of methodologies used in early childhood executive function research. Among the selected studies, seven were randomized controlled trials, including cluster, field experiments and a longitudinal study. Two studies employed quasi-experimental designs, while four were longitudinal studies. Additionally, three studies adopted qualitative or mixed-methods approaches, and one was a cross-cultural meta-analysis.

2.4 Interventions

The studies shared the common goal of enhancing EFs in preschool-aged children, although they differed significantly in their methodological approaches and theoretical frameworks. The interventions can be grouped into several broad categories: a) interventions based on motor activity and physical engagement, which integrate cognitively challenging movement or structured motor play into the classroom routine (Liu et al., 2022; Vazou & Mavilidi, 2021; Ureña et al., 2020; Tandom et al., 2020); b) interventions that leverage teacher-student interaction and classroom organization, focusing on the emotional and instructional climate as a mediator of EF development (An Kim, 2025; Cheng et al., 2025; Kellens et al., 2023; Violant-Holz et al., 2023; Xu et al., 2024); c) language and narrative-based

interventions, such as dialogic reading or structured storytelling aimed at fostering inhibition, cognitive flexibility, and working memory (Ruffini et al., 2021); d) curriculum and classroom-based interventions, where EF-related activities are embedded into broader instructional programs that also target academic or social-emotional skills (Rege et al., 2024; Størksen et al., 2023; Etokabeka, 2024; Keown et al., 2020; Vidal Carulla et al., 2021). Additionally, some studies explored the effects of music training (Lu et al., 2025) or bilingual code-switching practices (Sun et al., 2020) as indirect means of promoting EFs. Intervention durations ranged from a single session (as in acute effect studies) to long-term programs extending over several months or even an academic year, with the most common durations falling between 4 and 12 weeks. Out of the 17 studies reviewed, 10 included a control group while the remaining 7 employed designs without a comparison group.

2.5 Learning environment features

The studies investigated a wide range of ECLE, highlighting the diversity of physical, relational and pedagogical contexts in which EFs are supported. Many interventions took place within naturalistic preschool or kindergarten classrooms, often operating under specific curricular frameworks (e.g., Te Whāriki, Montessori, Reggio Emilia). Several studies emphasized emotionally supportive and well-organized classroom environments, particularly those in low-income settings (Cheng et al., 2025; Kellens et al., 2023), where teacher-child interactions, classroom routines and organizational structure were key elements. Some interventions were embedded in structured curriculum programs (Rege et al., 2024; Størksen et al., 2023) integrating EF-targeted activities within daily routines. Others used thematic approaches such as science-based play (Vidal Carulla et al., 2021), music sessions (Lu et al., 2025), dialogic reading (Ruffini et al., 2021) or bilingual classrooms (Sun et al., 2020). Physical activity also featured prominently, with some settings incorporating exergames (Liu et al., 2022) or movement-based play (Tandom et al., 2020; Ureña et al., 2020). Additionally, flexible and multimethod pedagogical environments were observed (Violant-Holz et al., 2023), where teachers adapted strategies to context, often balancing symbolic, functional and affective dimensions of learning.

2.6 Main Findings

The findings from the included studies can be grouped into three overarching and interconnected categories—Embodied Cognition; Emotion and Communication; and Structure, Curriculum and Environment—each encompassing specific thematic areas that illustrate how ECLE most effectively support the development of EFs in preschool-aged children (Table 2). For harmonic development and global well-being, it is essential that all these dimensions—physical, emotional, and cognitive—are simultaneously addressed within early learning environments.

Embodied Cognition

Strong evidence supports the effectiveness of interventions grounded in the principles of embodied cognition, that incorporate physical activity and movement-based learning into the daily routine. Liu et al. (2022) demonstrated that an exergame intervention involving motor coordination and cognitive challenge produced measurable gains in working memory, inhibition and cognitive flexibility after just four weeks. Ureña et al. (2020) further supported these findings, showing that brief, cognitively challenging movement breaks during class time led to immediate improvements in cognitive control and task-switching abilities. Similarly, Vazou and Mavilidi (2021) found that integrating short, daily sessions of physically engaging, cognitively rich activities significantly improved children's attention, with high fidelity of implementation reported by teachers. Keown et al. (2020) evaluated the "Red Light Purple Light" movement-based intervention designed to challenge children's inhibitory control and cognitive flexibility. Implemented during circle time, it required children to follow, remember and adapt to shifting verbal instructions. The study reported significant gains in cognitive flexibility immediately post-intervention and enhanced teacher-rated self-regulation at 4-month follow-up, with additional perceived improvements in language, listening and social skills. The study by Tandom et al. (2020) linked access to diverse gross motor equipment and structured indoor-outdoor play opportunities to improvements in behavioral self-regulation and a reduction in problem behaviors. Several studies illustrate how embodied symbolic practices, such as play, language, and music, further enhance EF development. Vidal Carulla et al. (2021) found that daily engagement in play-based science activities facilitated attention shifting and inhibitory control, while fostering collaborative meaning-making among peers. Lu et al. (2025), in a meta-analysis, reported small-to-moderate effects of music-based interventions—

lasting at least 12 weeks—on inhibition and working memory, especially in younger children. The rhythmic and repetitive nature of musical tasks was identified as particularly effective in enhancing attentional control and impulse regulation, underscoring how rhythmic bodily experiences can scaffold higher-order cognitive functions.

Emotion and Communication

Numerous studies emphasized the central role of emotionally attuned and communicatively rich teacher-child interactions in supporting the development of executive functions (EFs) during early childhood. The affective quality of the classroom environment—characterized by emotional warmth, relational stability, and responsive communication—has been consistently linked to improvements in self-regulation, attention, motivation, and persistence. Cheng et al. (2025) and An Kim (2025) demonstrated that emotionally supportive and well-organized classroom settings significantly enhance learning-related behaviors, especially those tied to attentional engagement and self-control.

Kellens et al. (2023) further showed that teacher-led activities embedded within emotionally secure routines promoted gains in working memory and planning, particularly when children experienced sustained, positive interactions. These findings underscore the importance of relational continuity, where children feel seen, heard, and emotionally safe—conditions that foster cognitive flexibility and sustained attention. Etokabeka (2024) identified six communicative techniques through which teachers nurture EF development: guiding, modelling, instructing, repeating, encouraging child-led exploration, and aligning activities with children's interests. Each technique involves intentional emotional presence and adaptive communication strategies that support the child's emerging capacity to regulate thoughts and behaviors. A meta-analysis by Xu et al. (2024) confirmed that children thrive in classrooms where relational closeness and affective regulation are prioritized. In such environments, emotional security and clear communication provide the scaffolding needed for developing cognitive control and attentional focus—reinforcing the interdependence between emotional experience, social connection, and executive functioning.

Structure, Curriculum and Environment

Structured routines and curriculum design emerged as key environmental factors in supporting the gradual maturation of EFs. Violant-Holz et al. (2023), Etokabeka

(2024) and Kellens et al. (2023) found that classroom routines embedded with emotionally and socially meaningful actions supported children's development of EFs because they provide a structured and predictable environment where children can practice skills such as self-regulation, inhibitory control, working memory and cognitive flexibility. This helps reduce cognitive overload and allows children to engage more effectively in EF-related behaviors such as planning, shifting and self-regulation, and highlights the importance of predictability and repetition within the environment. In addition, a well-structured environment fosters an atmosphere of autonomy and responsibility, which strengthens inhibitory control and the capacity to transition between tasks. Rege et al. (2024) suggested that intentional and consistent pedagogical planning—supported by teacher training and play-based EF activities—can raise the developmental quality of ECLE and promote executive functioning even when baseline structural quality is lacking.

Curricular approaches that integrate structured, cognitively rich activities have also proven effective. Ruffini et al. (2021) reported that dialogic reading interventions led to significant gains in cognitive flexibility and visuospatial working memory. Over the course of the program, children also showed steady progress in activities requiring inhibition and interference control, although these effects were more modest. Størksen et al. (2023) evaluated the Playful Learning Curriculum implemented in Norwegian ECEC and found significant post-intervention effects on early mathematics skills but not on working memory, suggesting that integrating guided, age-appropriate playful activities within a structured curriculum can enhance cognitive readiness for school. In the domain of language, Sun et al. (2020) found that teachers' use of intra-sentential code-switching was positively associated with children's development of cognitive flexibility. The children exposed to such bilingual interactions demonstrated improved ability to shift mental sets, as measured by the Dimensional Change Card Sort task.

2.6.1 Main Findings in preschool children with Special Educational Needs

About 50% of the studies specifically addressed vulnerable populations, including children with disabilities and those from low socioeconomic backgrounds, offering important insights into how tailored ECLE can serve both protective and promotive functions. An Kim (2025) found that although children with autism did not exhibit immediate EFs gains from attending pre-kindergarten, they demonstrated sustained improvements in working memory across the early elementary years,

suggesting long-term cognitive benefits of early participation in structured learning environments. Additional findings from Størksen et al. (2023) and Kellens et al. (2023) reinforce the importance of emotionally rich, relationally consistent, and scaffolded environments in supporting both typically developing and vulnerable learners.

Lu et al. (2025) confirmed that music-based interventions had a great impact on inhibitory control among low-SES children, particularly when delivered frequently and over sustained periods. Cheng et al. (2025) reported that preschoolers at developmental and socioeconomic risk showed enhanced attention, motivation, and engagement when immersed in emotionally and organizationally supportive classrooms. Xu et al. (2024) observed that while positive teacher-student interactions benefited all children, the effect sizes were smaller for children from disadvantaged socioeconomic backgrounds, indicating a need for more targeted strategies.

Kellens et al. (2023) demonstrated that a structured intervention embedded in daily activities not only stabilized but also improved planning and working memory specifically among low-SES children, while EF scores declined in control groups. Rege et al. (2024) revealed that a structured curriculum implemented in low-quality preschool settings was more effective in promoting EF development than in higher-quality ones, underscoring the compensatory value of pedagogical consistency in under-resourced contexts.

Overall, these studies collectively highlight that early childhood settings which combine emotional support, structural clarity and intentional pedagogical practices are not only beneficial for all children but are essential for mitigating early disadvantage and fostering equitable cognitive development.

3. Discussion

According to the main findings of included studies, the most effective ECLE for supporting EF development share several common features: they are physically active, emotionally rich, relationally stable, cognitively engaging. Interventions that embed EF practice within daily routines, guided physical play, narrative activities and music or language-based experiences appear especially beneficial. Furthermore, the importance of teacher-student interaction in fostering the development of executive functions and self-regulation is strongly confirmed by

Sankalaite et al. (2021), with particular emphasis on the impact of organizational and instructional support within the classroom environment. See Table 2.

Table 2. Summary of the results.

Category	Key thematic areas	Results
Embodied Cognition	Movement-based and physically active learning	• Working memory, inhibition and cognitive flexibility (Liu et al., 2022; Ureña et al., 2020; Keown et al., 2020; Vidal Carulla et al., 2021) • Attention (Vazou & Mavilidi, 2021) • Self-regulation and reduction in problem behaviors (Tandom et al., 2020) • Visuospatial working memory (Ruffini et al., 2021)
	Short cognitively challenging movement breaks	
	Gross motor equipment and in/outdoor play opportunities	
	Play-based learning	
	Music-based interventions*	
Emotion and Communication	Teacher-child interactions	• Self-regulation and attention (Cheng et al., 2025; An Kim, 2025; Størksen et al., 2023) • Working memory, planning skills and emotional control (Kellens et al., 2023) • Cognitive control and attentional engagement (Xu et al., 2024)
	Positive and emotionally supportive classroom climate*	
	Relational stability	
Structure, Curriculum and Environment	Structured and predictable environments*	• Self-regulation, inhibition, working memory and cognitive flexibility; reduction of cognitive overload; autonomy and responsibility (Violant-Holz et al., 2023; Etokabeka, 2024; Kellens et al., 2023; Rege et al., 2024; Sun et al., 2020) • Cognitive readiness for school (Størksen et al., 2023) • Attentional control and impulse regulation (Lu et al., 2025)
	Structured and predictable curriculum*	
	Play-based curriculum	
	Music and Linguistic environments*	

* Particularly effective in low-quality or low-SES educational contexts, and among children with Special Educational Needs.

It is particularly noteworthy that nearly all included studies report significant improvements in children's self-regulation skills and a reduction in behavioral difficulties. These outcomes suggest a strong connection between structured, emotionally supportive and developmentally appropriate settings and the enhancement of children's capacity to manage emotions, attention and behavior. Given the widespread concern in recent years about the increase in behavioral and

emotional challenges among young children, it seems both reasonable and urgent to infer that early educational interventions may play a crucial role in mitigating such difficulties. This points to the transformative potential of high-quality accessible learning environments not only in fostering EFs development, but also in promoting emotional well-being and social inclusion from the earliest years of life.
The findings align with the Sphere Model of Consciousness (SMC, Paoletti & Ben Soussan, 2019) linking the Narrative Self to structured, language-rich pedagogy and the Minimal Self to movement, routines and embodied learning. Activities like physical games and rituals support integration of emotional, attentional and bodily dimensions, guiding children from implicit awareness to reflective cognition and fostering self-regulation, attention and flexible thinking.
A limitation of this review lies in the exclusion of grey literature from the eligibility criteria, which may have led to the omission of relevant unpublished or practice-based findings. Furthermore, the authors chose to present the results narratively to ensure accessibility for educational professionals, reflecting the intention to translate neuroscientific evidence into informed educational practices.

4. Conclusions and practical applications

This systematic review, which to the authors' knowledge is the first to map school-based interventions aimed at supporting the development of EFs in early childhood, revealed a significant gap in the current literature. Despite the growing interest in executive functioning and early education, only a few studies have implemented and evaluated structured interventions within preschool settings.
The current findings align with theories of embodied cognition (Gomez Paloma, 2004) and the SMC (Paoletti & Ben Soussan, 2019), which highlighting the interconnectedness of emotional, bodily, and cognitive dimensions in early learning. Movement-based and emotionally supportive environments engage the whole child, physically, emotionally, and cognitively, fostering self-regulation, flexible thinking, and social-emotional growth.
Structured and emotionally supportive classroom environments, particularly those integrating physically active and play-based learning, were especially effective in supporting EF development among low-SES children, highlighting the potential of targeted educational practices to mitigate early disadvantage and foster equitable learning outcomes.

Based on the current review, several practical implications for educators emerge.

Embodied Cognition

1. Integrate physical activity and movement-based activities, such as short, cognitively challenging movement breaks, rhythmic tasks;
2. Use structured and repetitive musical activities to strengthen self-regulation and working memory;
3. Promote activities that intentionally involve the body (e.g., dance, mime, dramatic play) to support cognitive flexibility and sustained attention.

Emotion and Communication

1. Prioritize emotionally responsive teacher–child interactions through emotional presence, active listening, positive feedback, and adaptive communication strategies.
2. Ensure relational stability and create a safe, empathetic classroom climate to promote attentional engagement and emotional regulation.
3. Implement dialogic reading, shared storytelling, and cooperative play to enhance executive function development through social interaction.

Structure, Curriculum and Environment

1. Establish predictable environments with clear routines and meaningful rituals to reduce cognitive load and foster autonomy;
2. Design curricula that integrate playful, cognitively stimulating activities with a focus on progression and repetition;
3. Create flexible, inclusive, and accessible educational spaces that promote active participation, particularly for children with disabilities or from under-resourced contexts.

Early educational intervention generally appears to be a key strategy to unlock each child's developmental potential and to counteract the cumulative effects of poverty and vulnerability. Consequently, special attention should be paid to creating inclusive settings rich in stimuli and meaningful relationships, capable of supporting the development and well-being of even the most vulnerable children. Finally, a limited number of studies report early intervention outcomes for children with disabilities or those from low socioeconomic backgrounds. This scarcity highlights

the urgent need for future research that is both inclusive and contextually grounded. Acknowledging the complexity and diversity of ECLE, the authors call for new research directions that build on neuroscientific evidence to support the educational process. Such work should aim to co-design child-centered learning environments that are pedagogically intentional, emotionally responsive and capable of meeting both the general and specific needs of all children, thus promoting developmental equity from the earliest years.

Author contributions

NP supervised the project, offering continuous feedback and critical revisions throughout each stage of the review process. FMS prepared and submitted the PROSPERO registration, developed the list of search terms and conducted the literature search. FMS and TDBS jointly carried out the study selection, data extraction, interpretation of the results, and contributed to drafting and finalizing the manuscript. All authors read and approved the final version.

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